ELECTRICAL ENGINEERING

JUNE 1960
Vol. 79, No. 6

Contents

Transient Response and Ripple Effects in Thermoelectric Cooling Cells *N. Alfonso, A. G. Milnes* 443
The theoretical transient response and effects of sinusoidal ripple currents in thermoelectric cooling cells are analyzed

Semiconductor Materials for Research for Thermoelectric Power Generation up to 700 C *F. D. Rosi, J. P. Dismukes, E. F. Hockings* 450
Considerations of efficiency factors leading to materials selection to determine feasibility of power-generating efficiencies between 25 and 700 C

Thermoelectric Air Conditioning of Totally Enclosed Environments *G. D. Hudelson* 460
Thermoelectric air conditioning is discussed with the emphasis on the temperature and humidity control features

Operating Properties of Thermoelectric Generator Materials *M. G. Ryan, N. J. Stevens* 470
Measurement techniques for the selection of thermoelectric material and a brief exposition of the thermodynamics of thermoelectricity

Synthesis of Thermoelectric Generators *M. E. Talaat* 476
A guide is presented for the design of a thermoelectric generator which will yield a given output for a given source and heat sink

Design of a 100-Watt Thermoelectric Generator *T. M. Corry, W. C. Moreland, E. L. Strickland* 482
Practical problems involved in the construction of a 100-watt free-convection-cooled thermoelectric generator for the U. S. Air Force

Theoretical Bound on the Thermoelectric Figure of Merit *F. J. Donahoe* 488
The upper theoretical limit of the figure of merit z, a measure of the effectiveness of material as an active thermoelectric element

Progress and Problems in World Communication—Part I *E. I. Green* 494
Some important phases of the complex problem of planning for integrated and effective world communication are discussed

Field Treatment in Electric Shock Cases—II *W. B. Kouwenhoven, G. G. Knickerbocker, W. R. Milnor, J. R. Jude* 500
A presentation of additional data on the field treatment of men who have been rendered unconscious by electric shock

Moon-Reflection Studies with Bistatic Radar at 3,000 Mc *A. W. Straiton, C. W. Tolbert* 503
Measurements have been made to show the feasibility of receiving moon-bounce signals approximately one fourth the distance around the earth

A Practical Look at Information Theory—Part I *W. K. MacAdam* 508
Beginning a 2-part article on modern techniques of handling, generating, storing, and transmitting knowledge in its varied forms

CONTENTS CONTINUED

Courtesy NASA

THE COVER: Metallized plastic "sky mirror," 100 feet in diameter, is used in experiments on communication by means of reflecting satellites being conducted by the U. S. National Aeronautics and Space Administration, California Institute of Technology, Bell Telephone Laboratories, and others. Note comparative size of man and automobile near sphere. Story on p. 494.

Published monthly by American Institute of Electrical Engineers

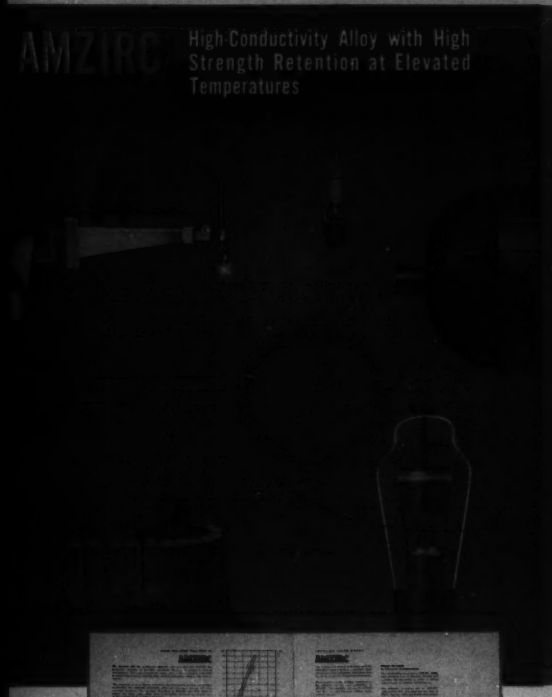
ELECTRICAL ENGINEERING. © Copyright 1960 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and annually by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York 18, N.Y., by the first of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

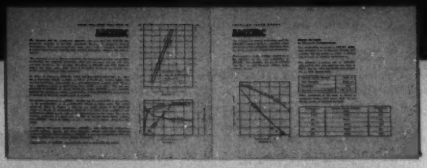
now available . . .

Free Technical Literature on Two Unconventional Copper Alloys

AMZIRC

High-Conductivity Alloy with High Strength Retention at Elevated Temperatures

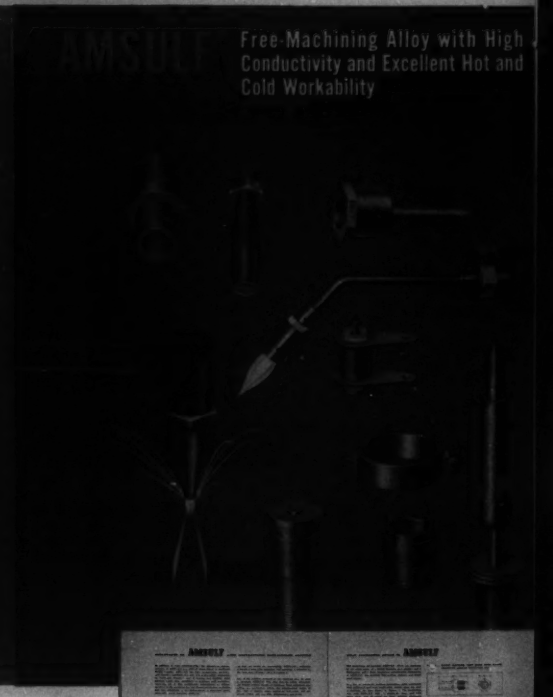


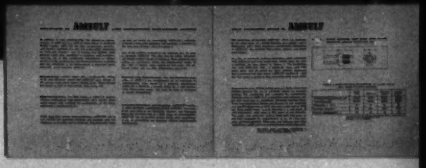


Eight-page booklet illustrated with charts and graphs. Gives metallurgical data on patented copper-zirconium alloy having tensile up to 52,000 psi at 400C plus room-temperature conductivity of 95% IACS; extreme notch toughness; exceptional hot and cold workability.

AMSULF

Free-Machining Alloy with High Conductivity and Excellent Hot and Cold Workability





Eight-page technical bulletin including tables and graphs. Provides physical and mechanical data of unique copper-sulfur alloy affording machinability rating of 90; rapid cutting rates and short chip formation; conductivity of 96% IACS; freedom from hydrogen embrittlement.

MAIL THIS COUPON TODAY!

Or if you are already familiar with AMZIRC and AMSULF and would like technical assistance in putting them to work for you, write the Technical Service Section.

AMCO DIVISION
American Metal Climax, Inc.
1270 Avenue of the Americas
Rockefeller Center, New York 20, N. Y.

Yes . . . I would like to know more about ☐ AMZIRC (Publication C-16) ☐ AMSULF (Publication C-17)

NAME _____

TITLE _____

COMPANY _____

STREET _____

CITY _____ ZONE _____ STATE _____

Contents Continued

Technical Paper Digests

Reliability Analysis for Aircraft Generators	J. T. Duane, L. J. Yeager	469
Short-Circuit Torques in Turbine-Generators	Paul Nippes	491
The Brushless Excitation System	R. W. Ferguson, R. Herbst, R. W. Miller	492
System Planning Production Cost Calculation	K. M. Dale, W. H. Ferguson, C. H. Hoffman, J. A. Rose	493
Recording Instrumentation for Steam Turbines	H. A. Harriman, D. M. Longenecker	499
Digital Solution of Network Short-Circuit Currents	A. L. Toalston	507
Self-Regulation in Magnetic-Transistor Amplifiers	C. E. Hardies, R. L. Van Allen	513
Transient Response in Feedback Amplifiers	J. H. Mulligan, Jr.	514

Departments

Institute Activities

- Philadelphia Section Will Be Host to Summer General Meeting . . . 515
- AIEE Future Meetings . . . 517
- Registration of About 650 Noted for Great Lakes District Meeting . . . 522
- South West District Meeting Keyed to Industrial Growth . . . 523
- AIEE Joint District Meeting Held at Charleston, W. Va. . . . 524
- Role of Nuclear Engineering Discussed at 1960 Nuclear Congress . . . 526
- Management Conference To Take Place September 15-16 . . . 528
- First Annual JACC Will Be Held September 7-9 . . . 520
- Lamme Medal 1960 Nomination Due November 1 . . . 536
- AIEE Personalities . . . 536
- Obituaries . . . 538

Engineering Societies Personnel Service, Inc . . . 26A

Of Current Interest

- Television Weather Satellite . . . 540
- Security Lifted on Radar Mapping Systems . . . 542
- Future Meetings of Other Societies . . . 543
- Rugged TV Camera . . . 544
- Super-Power Electron Gun . . . 545
- Design of Corner-Reflector Antennas . . . 546
- U. S. Army Signal Corps Centennial Year . . . 547
- Atomic Research Center Near Vienna . . . 550

New Books . . . 550
New Products . . . 8A
Industrial Notes . . . 50A
Trade Literature . . . 42A
Index to Advertisers . . . 70A

Statements and opinions given in articles appearing in *ELECTRICAL ENGINEERING* are expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on controversial matters. Published monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

Headquarters, 10th floor • Editorial Offices, 6th floor

33 West 39th Street, New York 18, N. Y.

J. H. FOOTE, President N. S. HIBSHMAN, Secretary

PUBLICATIONS DEPT W. F. Denkhaus, *Chairman*; N. H. Muller, *Vice-Chairman*; C. S. Rich, *Secretary*; E. W. Boehne, D. T. Braymer, T. H. Cline, Burke Frick, L. R. Gaty, Lenine Gonsalves, E. I. Green, E. T. B. Gross, W. R. Harris, C. T. Hatcher, D. L. Hemmenway, W. S. Hill, A. W. Kessler, C. W. Leihy, M. S. Merritt, F. W. Norris, F. C. Roberts, J. D. Tebo, J. I. Yesar, B. J. Wilson, P. G. Wallace.

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers, publication office Hildreth Press, Bristol, Conn. Editorial and advertising offices, 33 West 39th Street, New York 18, N. Y. Member subscription $6 per year nondeductible from dues; single copy 75 cents. Nonmember subscription $12 per year plus extra postage to all countries to which second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Bristol, Conn., under the Act of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P. L. & R. Act of February 28, 1925. June 1960. Vol. 79, No. 6. Number of copies this issue, 70,500.

Charles S. Rich
Editor and Manager of Publications

G. C. Baxter Rowe
Associate Editor

Editorial Assistants

G. Charitz

A. M. Fallert

G. Jaari

E. Jacobs

S. Walters

R. E. Whitlock

Advertising

J. S. Lopes
Middle Atlantic Manager
33 W. 39 St., New York 18, N.Y.
Tel: PEnnsylvania 6-9220

J. S. Holzer
Eastern Manager
33 W. 39 St., New York 18, N.Y.
Tel: PEnnsylvania 6-9220

E. R. Bollinger
Central Manager
3758 Cleveland-Massillon Rd.
West Richfield, Ohio
Tel: OLiver 9-4800

A. E. Del Gado
Mid-West Manager
1604 Chicago Ave.
Evanston, Ill.
Tel: GReenleaf 5-1132

T. P. Galavan
A. O. Dillenbeck, Jr.
Western Adv. Office
266 South Alexandria Ave.
Los Angeles 4, Calif.
Tel: DUnkirk 5-3991

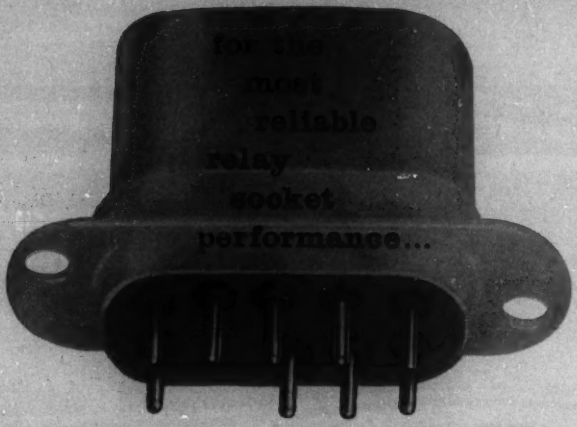
333 Kearny St., Rm. 310
San Francisco 8, Calif.
Tel: EXbrook 2-4073

J. C. Brettman
Southern Adv. Office
1915 E. Sunrise Blvd
Fort Lauderdale, Fla.
Tel: JA 2-6930

Waldo Schraubstader
Market Research Director

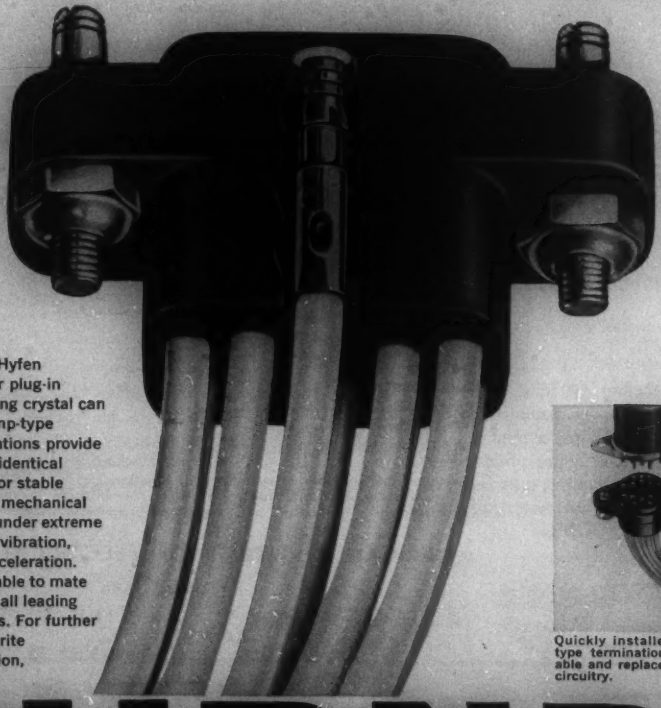
Frances Newman
Advertising Production Manager

Member
Audit Bureau of Circulations



PLUG-IN HYFEN® SOCKET

WITH CRIMP-TYPE, SNAP-LOCKED TERMINATIONS



a new line of Hyfen connectors for plug-in relays, including crystal can relays . . . crimp-type Hyfen terminations provide thousands of identical installations for stable electrical and mechanical performance under extreme conditions of vibration, shock, and acceleration. Sockets available to mate with relays of all leading manufacturers. For further information write Omaton Division,

Quickly installed individual crimp type terminations are easily removable and replaceable for flexibility of circuitry.

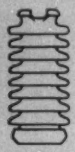
BURNDY

NORWALK, CONNECT. • BICC—BURNDY Ltd., Lancs., England • In Continental Europe: Antwerp, Belgium • TORONTO, CANADA

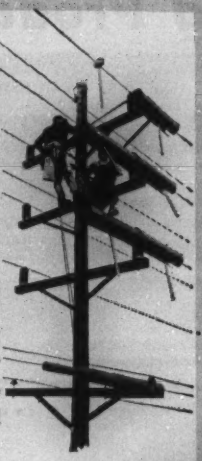
4 ways

to build economy
... and better performance
... in sub-transmission construction

TIE-HEAD LINE POST

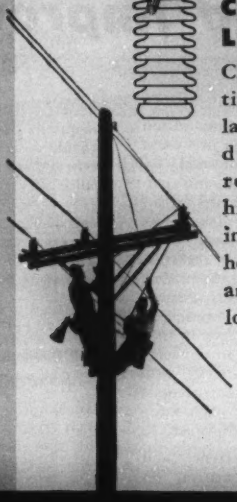


Up-to-date version of Lapp's original Line Post—the insulator with a 29-year service record of high-security operation. Inexpensive tie-wire installation provides a "mechanical fuse" when conductor breaks. New wide-throat conductor grooves on all units rated to 88 kv. The industry standard for most applications.

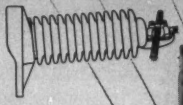


CLAMP-TOP LINE POST

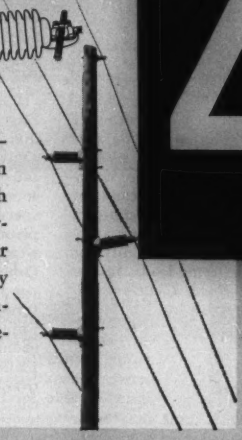
Clamp attachment particularly adapted to large aluminum conductors with armor rods. Best for use in hilly terrain. Simplest installation, easiest for hot-line maintenance, and eliminates tie-wire loosening.



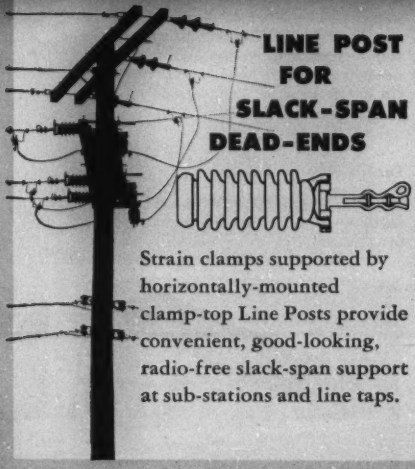
HORIZONTALLY-MOUNTED LINE POST



Save up to one-third in materials—more in labor of erection—with armless construction using Lapp Line Post with integral base-and-gain. Permits longer spans, larger conductors, greater safety margins. Eliminates contamination flashover, pole-top burning.



LINE POST FOR SLACK-SPAN DEAD-ENDS



Strain clamps supported by horizontally-mounted clamp-top Line Posts provide convenient, good-looking, radio-free slack-span support at sub-stations and line taps.

You'll find helpful data on use of a great variety of Lapp Line Post and Station Post Insulators in the new Lapp Catalog No. 8. Write for your copy.

Lapp Insulator Co., Inc.
LeRoy, New York.

Lapp

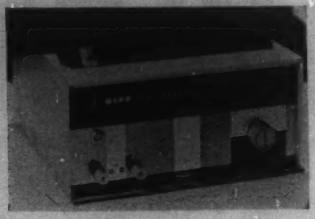
New and Improved Products . . .

Strip Chart Recorder . . .

This recorder features push-button operation and a nylon-tape pen drive that assures positive connection between pen and slide wire and permits the use of over-size strip or circular charts. The instrument monitors d-c signals in the 10- to 100-millivolt range and can be used for the measurement of temperature, pH, frequency, heat, solution conductivity, pressure, strain, and other variable sensing elements. *Beckman Scientific and Process Instruments Division, Fullerton, Calif.*

Multirange Microammeter . . .

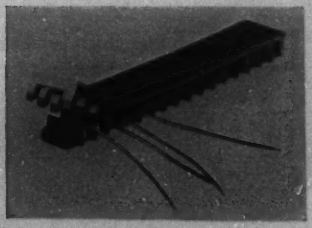
Measuring both current and voltage this extremely sensitive, yet robust, instrument combines the advantages of a galvanometer with those of a sensitive vacuum-tube volt-meter. Among its features are input resistance



of 500,000 ohms per volt on voltage ranges, low resistance on current ranges, and excellent linearity and stability. The heart of the instrument is a specially developed light spot galvanometer that is shock-proof and needs no clamping. *James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

Terminal Block Covers . . .

Wherever terminal blocks are used, there is an inherent danger of fires, short circuits, or the disruption of electric equipment if the blocks are left uncovered. These covers, made of Neoprene, Buna-N, or Silicate Rubber, provide a flexible casing with a wall between each terminal pole. The outer wall is slit to allow wires to be guided easily through to the terminals. The pegged edge of the terminal block fits into the receiving holes of the cover, securing it in position. *TA Mfg. Corp., 4697 Alger St., Los Angeles 39, Calif.*



Leak Detector . . .

Holes so microscopic that it would take 5 million years for 1 cubic inch of air to pass through can be spotted with this ultra-sensitive mass spectrometer leak detector. Designed to meet the critical needs for reliability in many electronic components, the instrument will find leaks in any evacuated chamber such as diodes, transistors, vacuum tubes, radiation counters, and other instruments used in missile technology. *Crosby-Teletronics Corp., Westbury, N.Y.*

Hoist Controller . . .

The *HWR* crane hoist controller operates on a-c power to give d-c performance. Static rectifiers are used to supply the d-c power to the series-wound motor and brake. Because of the inherent "blocking" characteristics of the rectifiers, this arrangement automatically increases motor stability for safe lowering of extreme loads. *Square D Co., 4500 Lee Road, Cleveland 28, Ohio.*

Field Plotter . . .

The electrolytic tank has been useful for solving awkward field problems in electromagnetism, fluid flow, and similar subjects. But the equipment has been expensive, requires skillful handling, and is usually a messy business. The Servomex Field Plotter Type *FP 92* is actually a 2-dimensional version of the electrolytic tank using a special type of resistance paper with silver electrodes painted on it. By means of the field plotter the operator can draw the map of potential and flow lines with convenience and no particular skill. *Servomex Controls Ltd., Crowborough, Sussex, England.*

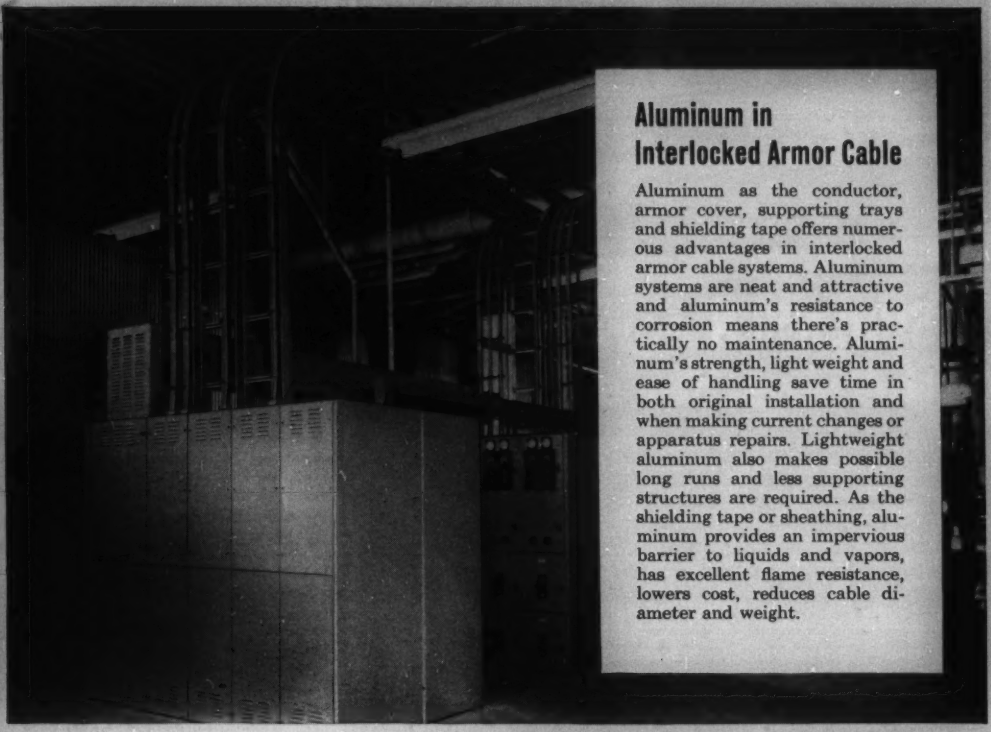
Dawn-Dusk Switch . . .

With this cover plate switch lights can be turned on automatically at dusk or off at dawn by means of a small photoelectric switching device. A time delay prevents turned off by a momentary flash or light. The totally enclosed device which will fit any standard outlet box has a maximum rating of 10-amperes 115-volts a-c. *Energy Kontrols, Inc., Geneva, Ill.*

Miniature Printer . . .

Printing speeds of more than 30 characters per second on 5/16-inch tape are attainable with this small printer. Only 9¼ inches long, with a self-contained paper supply, the printer fits a standard 3-inch instrument case. High speed and small size make it a useful printed for computer output and weapons system checkout devices. Other applications include dispatching control for police cars, fire trucks, trains, busses, taxi cabs, and other forms of transportation as well as for communication systems for private planes, for office use, and for use by troops in the field. *Potter Instrument Co., Sunnyside Blvd., Plainview, L. I., N. Y.*

(Continued on page 12A)



Aluminum in Interlocked Armor Cable

Aluminum as the conductor, armor cover, supporting trays and shielding tape offers numerous advantages in interlocked armor cable systems. Aluminum systems are neat and attractive and aluminum's resistance to corrosion means there's practically no maintenance. Aluminum's strength, light weight and ease of handling save time in both original installation and when making current changes or apparatus repairs. Lightweight aluminum also makes possible long runs and less supporting structures are required. As the shielding tape or sheathing, aluminum provides an impervious barrier to liquids and vapors, has excellent flame resistance, lowers cost, reduces cable diameter and weight.

Aluminum Conduit

Reynolds Aluminum Rigid Conduit cuts both installation and maintenance costs. It weighs only one-third as much as conventional conduit—installation is faster, easier. Aluminum conduit resists corrosion from most industrial atmospheres. Aluminum conduit is also non-magnetic, longer runs and smaller conductors are often possible.

REYNOLDS ALUMINUM

Watch Reynolds TV Shows: "BOURBON STREET BEAT" and "ADVENTURES IN PARADISE"; and "ALL STAR GOLF" (resuming in October)—ABC-TV

SORENSEN power rides the weather satellite!
The new weather satellite, TIROS, is one of the most remarkable space vehicles yet to take to the skies. For TIROS carries a complete TV transmitting system into space.
Built by RCA for the National Aeronautics and Space Administration, under technical direction of the U. S. Army Signal Corps, its mission is to televise cloud formations and transmit the pictures back to earth to aid weather forecasters.
Among the advanced electronic equipment in TIROS is a Sorensen dc to dc converter that transforms the output of the satellite's solar cells to voltages necessary for the satellite's complex electronic gear. Of course, this converter is both miniaturized and transistorized. It weighs only 20 oz. Unit-to reliability is vital to success of the project.
MORE THAN 130 MODELS
Read about the more than 130 different models of dc to dc converters offered by Sorensen in our new 36 page catalog ... plus a complete line of highly regulated dc power supplies, ac line voltage regulators, high voltage supplies, dc to 600,000 volts, frequency changers ... plus valuable reference data. Write for your copy to Sorensen, A Raytheon Company, South Norwalk, Conn.
Sorensen
CONTROLLED POWER PRODUCTS
A SUBSIDIARY OF RAYTHEON COMPANY
THE WIDEST LINE MEANS THE WISEST CHOICE

NEW PRODUCTS

(Con't from page 8A)

Stair Climber . . .

With this newly designed 2-wheeled hand truck, a 500-pound load can be easily transported up or down stairs at a rate of 18 feet per minute. Five feet long and 2 feet wide, the "Stair Cat" can be operated by one man guiding the truck. The device is electrically driven with two specially designed heavy-duty rubber belts providing traction. A 40-foot-long cord allows the operator to plug the truck into any nearby 115-volt outlet. *New Design and Development Corp., Lima, Ohio.*

Wideband Recorder . . .

Applying the same principle of a rotating head used so successfully in Videotape recorders for high speed transverse recording across a relatively slow moving tape, this latest military and scientific 2-channel recorder will provide a frequency spectrum response of 10 cycles to 4 mc. Amplitude is flat to within 3 db over this range. One unit, the *AR-300*, designed to be airborne, only records, while the *FR-300*, a ground unit, can record and reproduce. Using solid-state components throughout, the new system is also capable of recording two other channels of information with a lower frequency response of 200 cycles to 15 kc. *Ampex Corp., 934 Charter St., Redwood City, Calif.*

HX Cutout Line . . .

A new series of heavy-duty cutouts designated type *HX* have interrupting capacities ranging from 10,000 amperes at 7.8 kv to 6,000 amperes at 27 kv in the 100-ampere rating, and 12,000 amperes at 7.8 kv to 10,000 amperes at 15 kv in the 200-ampere rating. Dependable interruption over the full fault range is achieved by a highly efficient combination of expandable-cap and small-bore cartridge. *James R. Kearney Corp., 4236 Calyton Ave., St. Louis 10, Mo.*

Double-Emitter Transistor . . .

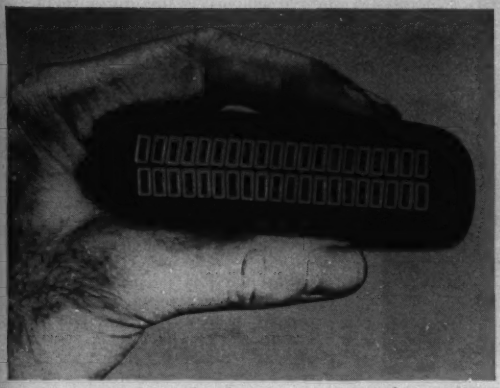
Believed to be the first practicable semiconductor of its kind, this component is expected to simplify the design of portable and automobile radios. Essentially a multijunction drift-field transistor, the device has two alloyed p-type emitters, an n-type base, and

(Continued on page 14A)

ANACONDA® COPPER METALS

FOR THE ELECTRICAL INDUSTRY

THE AMERICAN BRASS COMPANY • WATERBURY 20, CONN.



CROSS-SECTION of stator bar showing arrangement of 40 rectangular copper tube conductors which carry current and coolant—transil oil in present designs, water in units being planned.

LIQUID COOLANT enters the tubular conductors through a strand header at end of stator bars. *Above:* Header cut open to show construction. *Below:* Headers being installed on stator bars.

DO YOU KNOW THESE ELECTRICAL COPPERS?

ANACONDA LEADED COPPER-126 (Cu 99.00%, Pb 1.00%). Combines high conductivity, averaging 99% I.A.C.S., annealed, with excellent machinability, 80 on a scale in which Free-Cutting Brass is 100. Available in strip, rod, and bar form.

ANACONDA TELLURIUM COPPER-127 (Cu 99.49%, Te 0.50%, P 0.01%) offers high conductivity averaging 95% I.A.C.S., annealed, and machinability rating of 80. Available in rod, bar, extruded shapes, and die-pressed forgings. Particularly valuable where hot forging or hot working is combined with machining.

WRITE FOR Publication C-25, "Anaconda Copper for Electrical Conductors."

Liquid-cooled tubular copper conductors for stators can double generator ratings

In designing turbine-generator units for the ever larger blocks of power needed by the electric utility industry, General Electric scored a major advance by liquid-cooling the conductors in generator stator bars. The problem has been to increase generator ratings without increasing their physical size beyond the limitations of transportation.

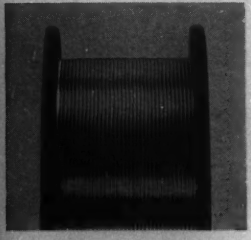
Occupying no more space than conventionally cooled 156,250-kva units of a few years ago, the first conductor-cooled G-E generator has a rating of 260,000 kva. And this new design is a significant step toward doubling generator ratings without an appreciable increase in frame size. It points the way to much larger machines – possibly as high as 750,000 kva.

The French Small Tube Division of The American Brass Company has recently supplied rectangular copper tube conductors for another generator of this design, which will have a rating of 221,000 kva. The tube was shipped in long coils.

For technical assistance in the design of hollow conductors, write The American Brass Company, Waterbury 20, Connecticut.

5970

Anaconda Welding Wire now available on 25-lb. spools for inert-gas consumable-electrode welding



For welding copper bus conductors and other fabrication by inert-gas consumable-electrode processes, Anaconda Copper-372 Welding Wire is now available in 25-lb. expendable spools. Carefully cleaned and layer-wound (left), it is shipped in a special carton. Sizes regularly available on spools: .035", .045", 1/16", 3/32" and 1/8". Other Anaconda copper-alloy welding alloys, such as Everdur®-1010 and Ambraloy -928, also are supplied on spools. For detailed information on Anaconda Welding Rods, write for Publication B-13.

Arnold Pulse Transformer Cores are individually tested under actual pulse conditions

The inset photograph above illustrates a special Arnold advantage: a 10-megawatt pulse-testing installation which enables us to test-prove pulse cores to an extent unequalled elsewhere in the industry.

For example, Arnold 1 mil Silectron "C" cores—supplied with a guaranteed minimum pulse permeability of 300—are tested at 0.25 microseconds, 1000 pulses per second, at a peak flux density of 2500 gausses. The 2 mil cores, with a guaranteed minimum pulse permeability of 600, receive standard tests at 2 microseconds, 400 pulses per second, at a peak flux density of 10,000 gausses.

The test equipment has a variable range which may enable us to make special tests duplicating the actual operating conditions of the transformer. The pulser permits tests at .05, .25, 2.0 and 10.0 microsecond pulse duration, at repetition rates varying anywhere from 50 to 1000 pulses per second.

This is just another of Arnold's facilities for better service on magnetic materials of all description. ● Let us supply *your* requirements.

Here's technical data on ARNOLD SILECTRON CORES

Bulletin SC-107 A contains design information on Arnold Tape Cores wound from Silectron (grain-oriented silicon steel). It includes data on cut C and E cores, and uncut toroids and rectangular shapes. Sizes range from a fraction of an ounce to more than a hundred pounds, in standard tape thicknesses of 1, 2, 4 and 12 mils.

Cores are listed in the order of their power-handling capacity, to permit easier selection to fit your requirements, and curves showing the effect of impregnation on core material properties are included.

7280

ADDRESS DEPT. EE-6

ARNOLD

SPECIALISTS In MAGNETIC MATERIALS

THE ARNOLD ENGINEERING COMPANY, Main Office: MARENGO, ILL.
BRANCH OFFICES and REPRESENTATIVES in PRINCIPAL CITIES

NEW PRODUCTS

(*Con't from page 12A*)

one p-type collector. The two emitters are processed so that they can function independently of one another. Improved automatic-gain-control characteristics and freedom from oscillator blocking under transient strong signals are two advantages to be expected from this development. *Radio Corporation of America, 30 Rockefeller Plaza, New York 20, N.Y.*

Flexible Wire . . .

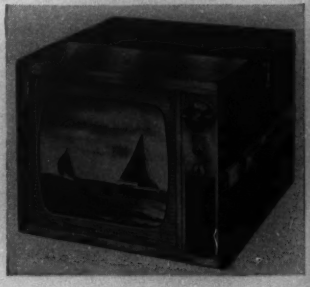
Elasticable can be stretched two to three times its relaxed length without losing any of its electrical properties. This feature makes it an ideal substitute for spiral or slack feed wire used to supply current to electrical parts that are in motion. Based on the old Chinese braided finger puzzle trick, wire is woven in braided fashion over a rubber core in such a way that it becomes elastic without stretching any of its component threads. Elongation of a single conductor is 300% while a multiple conductor can be stretched 275%. Braided nylon is used for outside insulation. *National Radio Co., Inc., Malden, Mass.*

Battery Thermostat . . .

Designed for direct immersion into the battery's electrolyte with the tip touching the top of the plate, this thermostat will prevent inefficency caused by low temperatures and damage due to excessive heat. Snap-action bimetal thermostat disks provide any desired external temperature control between −65 to +150 F. *D. W. Onan & Sons Inc., 2515 University Ave., S. E., Minneapolis 14, Minn.*

Portable TV . . .

Here is a truly portable, 28-pound, self-powered, all transistorized, 10-inch television receiver for those who like



Spaulding FIBRE FACTS FOR ENGINEERS NUMBER 3

How to Use Vulcanized Fibre for Electrical Insulation

By Earl A. Russell, Chief Engineer, Spaulding Fibre Company, Inc.

While all standard grades of Vulcanized Fibre can be used for many electrical insulating applications, the more exacting uses call for Spaulding's Electrical Insulation Grade — Armite.

Spaulding Armite is produced in thicknesses of 1/32 inch and under with a consistently higher dielectric strength than is available in other grades of fibre.

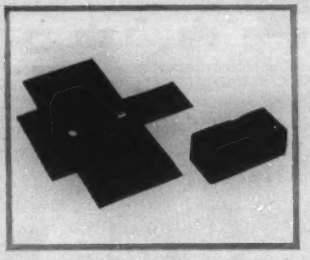
Special technical control of the manufacture of Armite makes it possible to combine this higher electrical quality with exceptional durability and forming qualities. Thus, Armite is particularly well suited for a wide range of both electrical and mechanical applications.

These uses include formed armature bonnets to insulate the windings from lead wires to the commutator, as well as for slot cell insulation in small armatures. Industry has also found extensive use for Armite in small, fractional horsepower motors. Here it is used in formed top sticks or wedges to insulate and anchor wires securely in the slots.

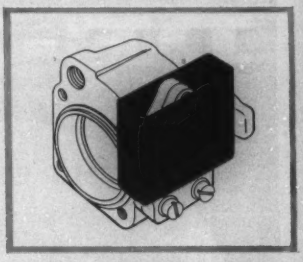
In "Barrier Insulation," the term used by Underwriters Laboratories for electrical insulation between live metal parts and adjacent live or ground metal parts, Armite finds one of its broadest applications. In this use, Armite insulators line the metal housing of electrical devices where space by itself is insufficient to provide gap insulation.

These Armite liners or "barriers" can be designed to accommodate almost any straight line contour. In .015" or .020" gauge Armite, fold lines are established economically by creasing in a punch press operation.

In thicker Armite, such as the more commonly used 1/32", score lines are punched in a fast punch press operation. This permits folding to fit neatly inside the housing box. Whether creased or scored, Spaulding ships these parts flat and ready to be formed easily by hand for insertion.



For barrier insulation as switch box liner, Armite is creased in punching operation for rapid hand forming.



For barrier insulation as removable terminal cover scored and formed, Armite is held in shape with eyelets and in place with indent at base.

In these, as in a vast range of other applications, Spaulding Armite makes it possible to design and execute finished assemblies of assured electrical qualities without sacrificing economy.

Armite's superior dielectric properties, coupled with good forming and structural stiffness, have made it the traditional choice of designers throughout the electrical industry.

SENT FOR YOURS YET?

SPAULDING'S FREE NEW REFERENCE BOOK DEVOTED EXCLUSIVELY TO ENGINEERING DATA ON VULCANIZED FIBRE

SPAULDING FIBRE COMPANY, INC.
361 Wheeler Street
Tonawanda, New York

Please bring my engineering file up to date by sending a free copy of Spaulding's "Vulcanized Fibre Engineering Data."

Name_____ Title_____

Firm_____

Address_____

City_____ Zone_____ State_____

SCAM
DE-LINE
THE ENGINEER'S

ANNUNCIATOR

GREATEST FLEXIBILITY IN THE FIELD

Available In Many Sequences

OR

BACK-LIGHTED NAME PLATE
BULL'S-EYE

AND

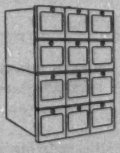
Twin-point can replace single point in field with no change in cabinet wiring.

Side By Side Or Stacked

DE-LINE modular design retains original custom cabinet appearance as system grows.

You save up to 50% panel area and still have full size legend plates.

DE-LINE plug-ins are self-policing.



AUXILIARY CONTACTS N.O.—N.C. standard with most plug-ins.

SAME PLUG-IN operates from N.O. or N.C. trouble contacts.

SEQUENCE OPTION after installation by means of independent slide switch at each point.

THE SCAM INSTRUMENT CORP.
Dept. C, 1811 West Irving Park Road
Chicago 13, Illinois
GRaceland 7-7850

REPRESENTATIVES IN ALL PRINCIPAL CITIES • COMPLETE MONITORING SYSTEMS FOR INDUSTRY

NEW PRODUCTS

(Con't from page 14A)

to view their television programs on the run. Designed to retail for about $250, the set is housed in a luggage-type cabinet and will operate on batteries that can be recharged by plugging into any 115-volt a-c outlet. *Emerson Radio & Phonograph Corporation, Jersey City 2, N.J.*

Low-Peak Fuse . . .

Capable of safety-interrupting fault currents up to 200,000 amperes, these high-interrupting capacity, long time-lag, and current-limitation fuses will allow normal current loads, motor starting currents, and other harmless overloads to pass. Yet on heavy fault currents, the fuse opens so rapidly the fault current cannot build up to damaging peaks. Starting with the main fuse and dropping down to the 15-ampere size, an adequate margin of safety allows for future growth of the electrical system without worry that the interrupting capacity of the fuse is inadequate. *Bussman Mfg. Division, McGraw-Edison Co., University at Jefferson, St. Louis 7, Mo.*

Steam Turbine Control . . .

An electro-hydraulic control system that is ten times faster and four times more sensitive than present mechanical controls, has been designed for medium capacity steam turbine generators. The system consists of a tachometer that senses turbine speed, a pressure transducer which senses extraction steam pressure, and a solid-state analog computer that directs hydraulic valve positioning devices for proper load and extraction flow demands. *General Electric Co., Schenectady 5, N.Y.*

Cutter-Crimper . . .

Cutting large electric cables in underground vaults and other closely confined quarters can be done cleanly and efficiently with this new tool. Both cutter and crimper are powered by a hydraulic ram in which oil pressure activates a hardened steel cutting blade. The forward edge of the tool has a hawk-like section which permits the operator to pry a cable away from flat surfaces, separating it from others in the group and seating it for the cutting and crimping operation. *The Welsbach Equipment Corp., 1500 Walnut St., Philadelphia 2, Pa.*

(Continued on page 21A)

NEW PRODUCTS

(Con't from page 18A)

Burglar Alarm . . .

A capacitance alarm designed to guard safes, filing cabinets, and other objects that can be insulated from the ground, triggers a signal when an intruder contacts or approaches to within a few inches of the protected object. Fully transistorized the device will automatically compensate for changes in temperature and humidity while retaining the required sensitivity. Power for 2,000 hours of operation is provided by dry cells, or the unit can be powered by a 12-volt bell transformer with the dry cells acting as standby power. *Walter Kidde & Co., Inc., Belleville, N.J.*

Load Controller . . .

With this motor load controller real loads can be sensed to actuate an alarm or shut down the machine if the load becomes too great due to malfunctioning. Most controls sense load by measuring current only, giving an approximate measure of torque within a limited range. This device, however, measures real load in kilowatts, indicating the percentage of rated load from zero to any overload percentage. The instrument will operate with single- or 3-phase systems at 110, 220, or 440 volts. *Seneca Falls Machine Co., 23 Fyfe Building, Seneca Falls, N.Y.*

Photoelectric Calibrator . . .

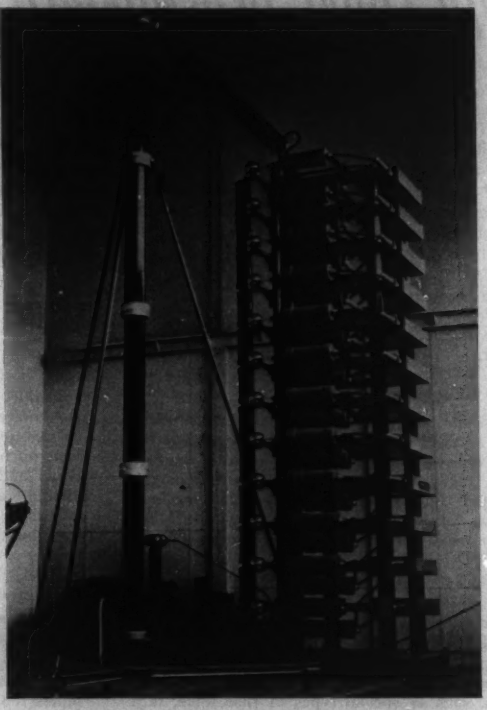
Series *6100* calibrator provides a fast, efficient method of adjusting photoelectric streetlight controls to operate at the desired foot-candle level. It is useful for acceptance testing of controls, basic trouble-shooting, and for checking and setting controls to conform to burning hour schedules. A matched pair of Weston photocells is connected from 0 to 5 and 0 to 10 foot-candles. A variable blue light inside the calibrator simulates actual operating conditions of a north-oriented control. *The Fisher-Pierce Co., 49 Pearl St., So. Braintree 85, Mass.*

HAEFELY

2,400,000 VOLTS

60 KILOWATT-SECONDS

IMPULSE SURGE GENERATOR



SIMPLICITY AND RELIABILITY

- Epoxy-sealed resistors not subect to dust or humidity.
- 200-kv charging rectifier is of the selenium type thereby assuring complete reliability.
- New surge-proof design. The epoxy-impregnated resistors will withstand the abnormal overvoltages resulting from the discharge of one series gap when the other gaps fail to discharge, without damage to resistors or capacitors.
- High-accuracy vltage measuring potentiometer.
- New co-axial lead arrangement reduces internal impedance to lowes' possible value.
- Many series-parallel comibnations of connections available. All connection changes are made on front of equipment only, readily visible to the operator.
- Differential protective control automatically trips the power supply in case of operator error in changing connections or any improper functin of the generator.

Write For Complete Information

SPECIALISTS IN HIGH VOLTAGE TESTING EQUIPMENT SINCE 1906

EMILE HAEFELY & CO. INC.

Box 7307 Portland 19, Oregon

HOW SOUTHERN STATES' BV-33-F CUTOUT CLEARS RESTRICTED OR HIGH FAULTS WITH EQUAL DEPENDABILITY

The complexities of today's distribution systems present a real challenge to the designers of cutouts. Industry requirements call for interrupting capacities up to three times higher than a few years ago. And yet the cutout must clear restricted faults with equal ease and sureness.

Large bore tubes, vented freely at both ends, will clear extremely high faults easily. Small bore tubes, vented at one end, will clear low faults easily. The big problem is to do both.

The Southern States BV-33-F Heavy Duty Cutout clears the complete range of fault currents with equal dependability—without damage to the cutout.

What About Single-Venting?

In single vented cutouts, the rocket effect of the tube, as gases are ejected, must be considered. Some type of shock absorber to cushion the fuse holder, as it tends to thrust upward, must be provided. But so far no practical recoil mechanism has been devised that can fully absorb the violent recoil action. Thus a substantial amount of shock is transmitted to the mounting, insulator, bracket, and cross arm.

As interrupting capacities on single-vented cutouts are increased, bore diameters become critical. If it is large enough to handle high faults, it may provide only borderline protection on restricted faults. Resorting to some extraneous means, such as special types of fuse links, is a dangerous concession to security—as there is no assurance of proper fusing in the field.

What About Controlled Venting?

Providing a small vent hole in the top hardware to permit a limited amount of gas to escape is not the solution either. This practice was dropped by Southern States long ago, when it was found that the hole became enlarged after each operation, endangering proper clearance of low faults.

Here's the Answer

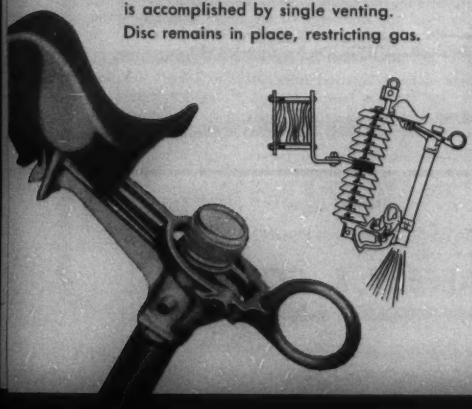
The BV-33-F offers all of the advantages and none of the disadvantages of single-venting or controlled-venting. This is accomplished with an economical expendable cap which confines gases on restricted faults, but allows them to double vent on high faults. Forces inside the tube are equal and opposite. Stress on the mounting is virtually eliminated. The cutout can operate time and time again without loss of efficiency. There is no built-in battering ram—no intricate mechanism, or springs to worry about. And any standard EEI-NEMA fuse link will provide positive operation every time.

Utilities throughout the nation are finding the BV-33-F a practical, workable solution to cutout problems.

Get complete information from your Southern States representative, or write for Bulletin 580C.

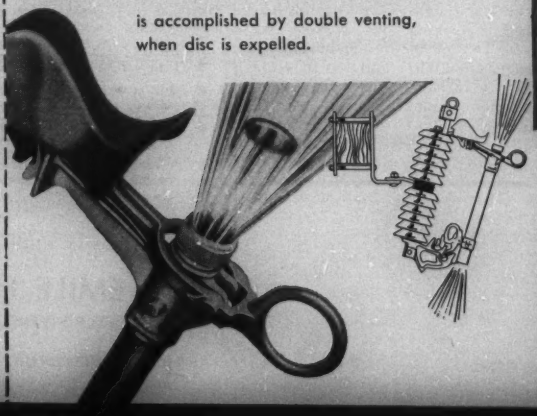
LOW FAULT CLEARANCE

is accomplished by single venting.
Disc remains in place, restricting gas.



HIGH FAULT CLEARANCE

is accomplished by double venting,
when disc is expelled.



Transient Response and Ripple Effects in Thermoelectric Cooling Cells

N. ALFONSO

A. G. MILNES
MEMBER AIEE

The theoretical transient response and the effects of sinusoidal ripple currents in thermoelectric cooling cells under various load conditions are analyzed.

THERMOELECTRIC refrigeration with reasonable efficiency is achievable with recently developed materials, and such techniques[1,2] and materials are currently the subject of much study. However, apart from an examination by Stilbans,[3] restricted to a condition of no thermal loading, little attention has been paid to the transient response of such systems. In this article, the theoretical transient response of a thermoelectric cooling cell is studied under various loading conditions for a step function of current, and for the effects of sinusoidal ripple currents.

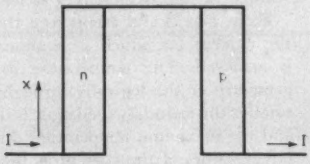


Fig. 1. A p-n thermocouple.

STEADY-STATE CONDITIONS

A TYPICAL THERMOCOUPLE with branches of p-type and n-type semiconductor material is represented in Fig. 1. The two legs of the thermoelement are assumed to be joined by a metallic bridge of negligible electrical resistance and high thermal conductivity. The direction of the direct current shown produces cooling effect at the p-n junction on the top.

For simplicity, the physical parameters such as thermal conductivity and electrical resistivity of the two legs are assumed to be equal. When the typical semiconductor character affects the physical properties, the sign only is assumed to change, for instance the thermoelectric power is taken as $+\alpha$ for p-type and $-\alpha$ for n-type. The values of the material parameters (thermal conductivity, electrical resistivity, specific heat, density, etc.) are assumed average values over the working range of temperature and will be considered as constant throughout the analysis. The thermoelectric power is assumed not to vary significantly with temperature within the operating interval and, therefore, the Thomson effect is neglected.

The configuration of the thermoelectric cooling cell under study corresponds to that of Fig. 2. The cold junction is inside the insulating chamber C and the temperature of the hot junction is kept constant by passing a cooling fluid at sufficient velocity.

The temperature of the metallic bridge is considered to be uniform by virtue of its high thermal conductivity, and equal to that of the cold p-n junction. The effect of this bridge is neglected in the steady state, but may be taken into account as an additional thermal inertia during the transient state. The temperature of the air inside the chamber and at the inner walls is considered to be uniform and equal to the cold-junction temperature. This condition is acceptable if vigorous stirring of the air in the chamber is assumed.

Side losses from the thermoelectric elements are assumed negligible, so the heat flow may be considered unidirectional along the legs. The temperature problem in the insulating enclosure is also treated as a unidimensional one so corner effects are neglected. In Fig. 2, l is the length of the leg, and a the thickness of the insulating wall of the chamber.

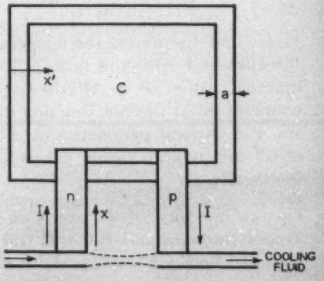


Fig. 2. Thermoelectric cooling cell.

Full text of conference paper CP60-174, presented at the AIEE Winter General Meeting, New York, N. Y., Jan. 31–Feb. 5, 1960. Recommended for publication by the AIEE Solid State Devices Committee.

N. Alfonso, formerly with the Carnegie Institute of Technology, Pittsburgh, Pa., is now with the Westinghouse Electric Corporation, Pittsburgh, Pa.; A. G. Milnes is with the Carnegie Institute of Technology.

This work was supported by Office of Naval Research Contract NONR 760(09).

The differential equation for the temperature in the insulation, for steady-state conditions, is

$$\kappa_2 \frac{d^2 T_1}{d x'^2} = 0 \tag{1}$$

If for the insulation walls boundary layer film effects are ignored, the boundary conditions for equation 1 are

$$\text{at} \quad x = 0, \qquad T_1 = T_0 \tag{2}$$

$$\text{at} \quad x = a, \qquad T_1 = T(l) \tag{3}$$

where

T_0 = ambient temperature, assumed equal to the constant temperature of the hot junctions

$T(l)$ = temperature of the cold junction

The differential equation for the temperature in the legs is

$$\kappa_1 \frac{d^2 T}{dx^2} + E r i^2 = 0 \tag{4}$$

where

E = conversion factor between watts and calories per second
= current density, amperes per cm^2

with the boundary conditions:

$$\text{at} \quad x = 0, \qquad T = T_0 \tag{5}$$

$$\text{at} \quad x = l, \qquad -2\zeta_1 \kappa_1 \left.\frac{dT}{dx}\right|_{x=} - \zeta_2 \kappa_2 \left.\frac{d T_1}{dx'}\right|_{x'=a} = 2\zeta_1 i \alpha E T(l) \tag{6}$$

From equations 4, 5, and 6, the temperature of the cold junction is

$$T(l) = \frac{E\left(\frac{r}{\kappa_1}\frac{I^2}{2}\frac{l^2}{\zeta_1^2} - I\frac{\alpha}{\kappa_1}\frac{l}{\zeta_1}T_0\right)}{1 + I\frac{\alpha}{\kappa_1}\frac{l}{\zeta_1}E + \frac{\zeta_2\kappa_2}{2a\kappa_1}\frac{l}{\zeta_1}} + T_0 \tag{7}$$

If the chamber is perfectly insulated (no heat leakage through the walls), this expression reduces to

$$T(l) = \frac{E\left(\frac{r}{\kappa_1}\frac{I^2}{2}\frac{l^2}{\zeta_1^2} - I\frac{\alpha}{\kappa_1}\frac{l}{\zeta_1}T_0\right)}{1 + I\frac{\alpha}{\kappa_1}\frac{l}{\zeta_1}E} + T_0 \tag{8}$$

Figs. 3 and 4 represent the temperature drop ΔT versus the current I with the ratio l/ζ_1, as a parameter, for different values of a. All the curves correspond to a temperature at the hot junction of 300 degrees Kelvin and the physical parameters of the thermoelectric material are typical values taken from the literature; specifically,

Electrical resistivity $r = 10^{-3}$ ohm $\times$ cm
Thermal conductivity $\kappa_1 = 0.47 \times 10^{-3}$ cal $\times$ deg^{-1} $\times$ cm^{-1} $\times$ sec^{-1}
Thermal diffusivity $\delta_1 = \kappa_1/c_1\xi_1 = 10^{-3}$ cm^2 $\times$ sec^{-1}

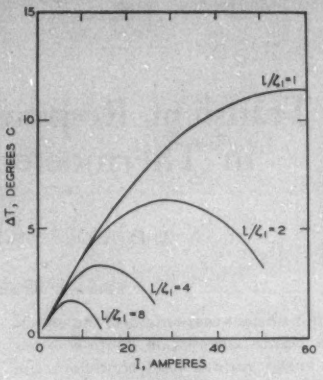


Fig. 3. Steady-state temperature drop as a function of the current with l/ζ_1 as a parameter. Chamber insulation $a = 1$ cm, $\zeta_2 = 600$ cm^2.

where c_1 = specific heat, cal $\times$ gm^{-1} $\times$ deg^{-1}
ξ_1 = density of material, gm $\times$ cm^{-3}
Thermoelectric power $\alpha = 2 \times 10^{-4}$ volts $\times$ deg^{-1}
Figure of merit $Z = 2.1 \times 10^{-3}$ deg^{-1}

The thermal conductivity and diffusivity of the insulating material are taken as follows:

Thermal conductivity $\kappa_2 = 10^{-4}$ cal $\times$ cm^{-1} $\times$ deg^{-1} $\times$ sec^{-1}
Thermal diffusity $\delta_2 = 2 \times 10^{-3}$ cm^2 $\times$ sec^{-1}

For the surface area ζ_2 of the chamber, a value of 600 square centimeters is chosen, which corresponds to a volume of approximately 1 liter.

From Figs. 3 and 4 it is seen that there is a value of the current for which a maximum temperature drop is achieved. The temperature drop depends on the geometry of the leg only through the ratio l/ζ_1. The smaller the ratio l/ζ_1 the larger is the temperature drop, and the maximum temperature difference is reached at larger values of the current as the ratio l/ζ_1 decreases. Fig. 4 for the condition of no heat loading shows that the maximum temperature drop achievable is independent of the ratio l/ζ_1, and the current at which the maximum occurs is inversely proportional to that ratio. Clearly, as the heat leakage through the walls of the chamber increases, the temperature drop becomes smaller.

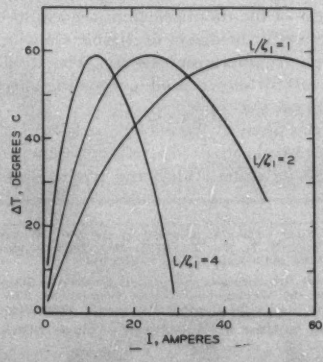


Fig. 4. Temperature drop with no heat leakage across the insulation.

TRANSIENT RESPONSE ANALYSIS FOR STEP-FUNCTION CURRENT PULSE

When a step-function current pulse is applied to the refrigerator, at time $t = 0$, there is a transient period until steady-state conditions are reached. At the initial instant the whole system is at the same temperature, which is assumed to be the ambient temperature T_0.

The differential equation for the temperature as a function of x' in the insulation is

$$\frac{\partial T_1}{\partial t} = \delta_2 \frac{\partial^2 T_1}{\partial x'^2} \tag{9}$$

with the initial condition

$$\text{at} \quad t = 0 \qquad T_1(0, x') = T_0 \tag{10}$$

and boundary conditions,

$$\text{at} \quad x' = a \qquad T_1(t, a) = T(l) \tag{11}$$

$$\text{at} \quad x' = 0, \qquad T_1(t, 0) = T_0 \tag{12}$$

In the thermoelectric leg, the differential equation for the temperature is

$$\frac{\partial T}{\partial t} = \delta_1 \frac{\partial^2 T}{\partial x^2} + E \gamma i^2 \tag{13}$$

with the initial condition

$$\text{at} \quad t = 0. \qquad T(0, x) = T_0 \tag{14}$$

and boundary conditions

$$\text{at} \quad x = 0, \qquad T(t, 0) = T_0 \tag{15}$$

$$\text{at} \quad x = l, \; -2\zeta_1 \kappa_1 \left.\frac{\partial T}{\partial x}\right|_{x=} - \zeta_2 \kappa_2 \left.\frac{\partial T_1}{\partial x'}\right|_{x'=a} = 2\zeta_1 t \alpha E T(l) + mc \frac{\partial T}{\partial t} \tag{16}$$

The presence of the last term in equation 16 accounts for the heat per unit time removed from the chamber during the transient process, m being the mass, in grams, of the material contained in the chamber and c its specific heat (cal $\times$ gm^{-1} $\times$ deg^{-1}). The current pulse may be expressed mathematically by the function

$$I(t) = I f(t) \tag{17}$$

where I is the absolute magnitude of the pulse and $f(t)$ is the unit step function defined in the following way

$$\begin{aligned} f(t) &= 0 \quad \text{if} \quad t < 0 \\ f(t) &= 1 \quad \text{if} \quad t > 0 \end{aligned} \tag{18}$$

Laplace transform methods have been adopted in the solution of this time dependent boundary value problem. Taking the L-transform of equations 9 and 13, the differential equations to be solved are equations where the independent variable is the space-variable and the complex frequency s appears as a parameter. The L-transforms of equations 9, 11, 12, 13, 15, and 16 are

$$s\mathcal{T}_1(x', s) - T_0 = \delta_2 \frac{\partial^2 \mathcal{T}_1(x', s)}{\partial x'^2} \tag{19}$$

$$\mathcal{T}_1(a, s) = \mathcal{T}(l, s) \tag{20}$$

$$\mathcal{T}_1(0, s) = \frac{T_0}{s} \tag{21}$$

$$s\mathcal{T}(x, s) - T_0 = \delta_1 \frac{\partial^2 \mathcal{T}}{\partial x^2} + \frac{E\gamma i^2}{s} \tag{22}$$

$$\mathcal{T}(0, s) = \frac{T_0}{s} \tag{23}$$

$$-2\zeta_1 \kappa_1 \left.\frac{\partial \mathcal{T}}{\partial x}\right|_{x=} - \zeta_2 \kappa_2 \left.\frac{\partial \mathcal{T}_1}{\partial x'}\right|_{x'=a} = 2\zeta_1 i \alpha E \mathcal{T}(l, s) + mc\left[s\mathcal{T}(l, s) - T_0\right] \tag{24}$$

where the symbols $\mathcal{T}_1$ and $\mathcal{T}$ represent the L-transforms of T_1 and T respectively.

Solving equation 22 and determining the integration constants by applying the boundary conditions, the temperature in the leg as a function of x is obtained in the s-plane.

Making $x = \zeta$, the cold junction temperature results. This gives

$$\mathcal{T}(l, s) = \frac{\dfrac{\gamma i^2}{s^2} 2\zeta_1 \kappa_1 F \sqrt{\dfrac{s}{\delta_1}} \left[\cosh \sqrt{\dfrac{s}{\delta_1}}\, l - 1\right] - 2\zeta_1 \alpha i E \dfrac{T_0}{s} \sinh \sqrt{\dfrac{s}{\delta_1}}\, l}{2\zeta_1 \kappa_1 \sqrt{\dfrac{s}{\delta_1}} \cosh \sqrt{\dfrac{s}{\delta_1}}\, l + \left[2\zeta_1 \alpha i E + \zeta_2 \kappa_2 \sqrt{\dfrac{s}{\delta_2}} \coth \sqrt{\dfrac{s}{\delta_2}}\, a + mcs\right] \sinh \sqrt{\dfrac{s}{\delta_1}}\, l} + \frac{T_0}{s} \tag{25}$$

It is convenient at this point to introduce a dimensionless complex frequency. This new variable, which will be written S, is defined by

$$S = \frac{l^2}{\delta_1} s \tag{26}$$

Expressing equation 25 as a function of S and introducing the following notation

$$\begin{aligned} A &= \frac{\alpha}{\kappa_1} I \frac{l}{\zeta_1} F & C &= \sqrt{\frac{\delta_1}{\delta_2}} \frac{a}{l} \\ & & D &= \frac{mc}{2\zeta_1 c_1 \zeta_1 l} \\ B &= \frac{\kappa_2}{2\kappa_1} \frac{\zeta_2}{\zeta_1} \sqrt{\frac{\delta_1}{\delta_2}} & G &= \frac{\gamma}{\kappa_1} EI^2 \left(\frac{l}{\zeta_1}\right)^2 \end{aligned} \tag{27}$$

$$\left[\mathcal{J}(l,S) - \frac{l^2}{\delta_1}\frac{T_0}{S}\right] = \frac{l^2}{\delta_1} \times$$

$$\left\{\frac{G\dfrac{\cosh\sqrt{S}-1}{j\sqrt{S}} - A\,T_0\dfrac{\sinh\sqrt{S}}{j}}{(-S)\left[j\sqrt{S}\cosh\sqrt{S} - (A+B\sqrt{S}\coth C\sqrt{S}+DS)\dfrac{\sinh\sqrt{S}}{j}\right]}\right\}$$

$$= \frac{l^2}{\delta_1}\mathcal{J}^*(S) \tag{28}$$

By taking into account the change of scale theorem of the Laplace transform theory, the inverse transform of $\mathcal{J}^*(S)$ will give the time-dependent temperature drop, the time being a reduced time, dimensionless, given by

$$\tau = \frac{\delta_1}{l^2}t \tag{29}$$

That is,

$$\Delta T(\tau) = \mathcal{L}^{-1}[\mathcal{J}^*(S)] \tag{30}$$

The inversion of $\mathcal{J}^*(S)$ has been accomplished by expanding it in partial fractions of the form $R_i/S - S_i$, where S_i are the poles of $\mathcal{J}^*$ and R_i the residues of $\mathcal{J}^*$ at these poles.

Hence,

$$\mathcal{J}^*(S) = \sum_0^\infty \frac{R_i}{S - S_i} \tag{31}$$

Equation 28 may be rewritten using circular functions. The pole of the function at $S = 0$ gives the steady-state expression for the temperature drop, according to the final value theorem of the L-transform. Therefore, if the summation of equation 31 extends from 1 to ∞, that is if $R_0/S - S_0 = R_0/S$ is excluded, the resulting expression will only give the transient component.

To simplify the calculation a new variable is now introduced, defined by

$$u = \sqrt{-S} \tag{32}$$

and $\mathcal{J}^*(S)$ becomes

$$\frac{G\dfrac{\cos u - 1}{u} + A\,T_0 \sin u}{u^2\left[u\cos u + (A + B\,u\cot Cu - Du^2)\sin u\right]} \tag{33}$$

If no heat leakage takes place through the insulation, the corresponding expression is

$$\frac{G\dfrac{\cos u - 1}{u} + A\,T_0 \sin u}{u^2\left[u\cos u + (A - Du^2)\sin u\right]} \tag{34}$$

The transient temperature drop is given by

$$T(\tau) - T_0 = \Delta T_{ss} + \sum_{i=1}^{\infty} R_i\,\epsilon^{-u_i^2\,\tau} \tag{35}$$

where u_i are the roots of the transcendental equation

$$u\cos u + (A + Bu\cot Cu - Du^2)\sin u = 0 \tag{36}$$

and R_i the residues. In the case of no heat leakage the transcendental equation to be solved is

$$u\cos u + (A - Du^2)\sin u = 0 \tag{37}$$

In order to find the roots of these equations, a first approximation may be obtained graphically and using the graphical solutions as trial points Newton's method may be applied to give the roots with more accuracy. An IBM *650* digital computer was used for this purpose and consistently good results were obtained. Once the roots of these transcendental equations are known, the corresponding residues are computed.

It is more convenient for representation purposes to express the transient temperature difference in a normalized form, that is,

$$\frac{T(\tau) - T_0}{\Delta T_{ss}} = \frac{\Delta T_{ss} + \sum_1^\infty R_i\,\epsilon^{S_i\tau}}{\Delta T_{ss}} = 1 + \sum_1^\infty \frac{R_i}{\Delta T_{ss}}\,\epsilon^{S_i\tau} \tag{38}$$

With u_i and R_i known, sufficient data are available to evaluate equation 38. This involves a series of terms, but it is in most cases so rapidly convergent that two or three terms suffice to obtain fairly accurate results. However for very small times the series does not converge so fast and more terms have to be taken, so provision was made in programming to take as many terms as required to secure good convergence.

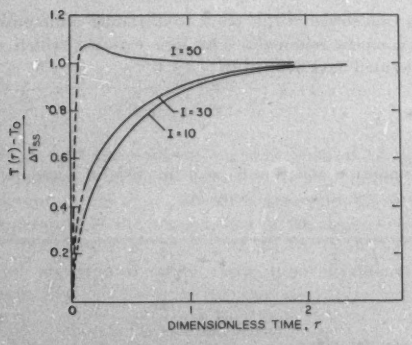


Fig. 5. Normalized transient response for $l = 2$ cm, $\zeta = 1$ cm², and $a = 1$ cm.

DISCUSSION OF COMPUTED RESULTS

FIGS. 5 AND 6 represent the normalized temperature response with the step-function current as a parameter for $\zeta = 2$ centimeters, $\zeta_1 = 1$ square centimeter. In Fig. 5 the width of the insulating wall is $a = 1$ centimeter. Fig. 6 represents the transient curves when no heat leaks through the insulation. The thermal inertia assumed corresponds to 1 liter of air.

The speed of response increases with current, since the Joule heat is generated throughout the volume of the thermoelement and thus takes time to propagate

by conduction, whereas Peltier cooling occurs at the cold junction as soon as the current is turned on (in the macroscopic model which is being considered). Thus, it is clear that the larger the current (more Peltier cooling) the faster is the response, and this is true in all ranges of current, even though what is gained in speed of response by increasing the current a certain amount depends on the current range. In the 50-ampere curve the response is so fast that overshoot is exhibited. When the system is better insulated, the speed of response grows with the current more smoothly, and the over-all transient response is slowed down considerably, since the insulation must also be cooled; however, the maximum temperature drop improves. With certain parameter proportions, an operating point slightly to the right of the maximum on the static curve may make the improvement in speed of response worthwhile even though it is achieved at the cost of some reduction in cooling effect.

To see the influence of changing the length of the thermoelement on the transient response, the graphs have to be interpreted rather carefully, since the reduced time τ is inversely proportional to the square of the length of the thermoelement. For a comparison of response times, the rise time may be taken as the time taken by the system to reach 90% of the steady state. The effect of doubling the length of the thermoelement in the case of good insulation, with the current constant, is to slow down the transient response. This conclusion applies to a well-insulated system, but when the system is not well insulated the effect of doubling the length l with the current I constant, is not always a reduction in speed of response. For instance, if the operating current is 50 amperes when the length changes from 1 to 2 centimeters the response is faster, to the point that overshoot is exhibited. Looking at the steady-state curves it is seen that the 50-ampere point is on the descending portion of the curve and far from the maximum for $l/\zeta_1 = 2$, whereas the point corresponding to the same current is still on the increasing portion of the curve for $l/\zeta_1 = 1$.

TURN-OFF TRANSIENT RESPONSE

In some instances it may be of interest to know the time required by the refrigerator to reach equilibrium from the instant at which the current is turned off.

If the origin of time is taken as the instant at which the current is turned off and the refrigerator was in steady state before the switching, the initial condition of the problem will be the result of the steady state analysis. Application of the Laplace transformation methods to this situation gives the temperature at the cold junction as a function of S and performing the inversion, the temperature in the time domain is obtained.

In those cases in which overshoot takes place during the transient, undershoot exists during the recovery. Numerical evaluation when $I = 50$ amperes, $l = 2$ centimeters, $\zeta_1 = 1$ square centimeter, for instance, gives

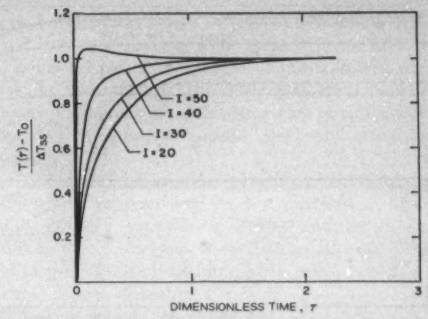


Fig. 6. Normalized transient response assuming no heat leakage across the insulation.

a recovery time of the same order of magnitude as the rise time, and the overshoot and undershoot are comparable. These and other studies for various repetitive pulse-current conditions are described elsewhere.[4]

RESPONSE TO AN INCOMPLETELY SMOOTHED DIRECT CURRENT

In the steady-state analysis the operating current was assumed to be a constant direct current furnished by a battery or a well-filtered power supply. But it is of interest to study the effect on the refrigerator performance of irregularities present in the d-c wave, particularly those coming from a power supply as ripple. This ripple varies in shape, depending on its cause, and the study of the refrigerator performance based on the exact form of the ripple tends to be impractical. The most common ripple wave shape is that at the output of a full-wave single-phase rectifier bridge and filter. This contains a fundamental frequency twice the frequency of the a-c line and numerous harmonics, of which only the first few may be significant. In the treatment that follows only the fundamental frequency component is considered.

A second point of importance is that thermal transients are normally slow in comparison with the rapidly varying form of the current, whatever its shape may be, and a time-dependent analysis tracing the temperature during the a-c cycle would be rather involved and of limited interest. Since any temperature-measuring device is likely to give cyclic averages, the analysis that follows is based on the average temperature over the cycle.

The general time-dependent differential equation when averaged over a cycle may be replaced by

$$\frac{\partial \bar{T}}{\partial t} = \delta \frac{\partial^2 \bar{T}}{\partial x^2} + E\gamma i^2 \tag{39}$$

As the main interest in a situation of this sort is in what happens in the steady state, equation 39 will be written in its time-independent form,

$$\delta \frac{\partial^2 \bar{T}}{\partial x^2} + E\gamma i^2 = 0 \tag{40}$$

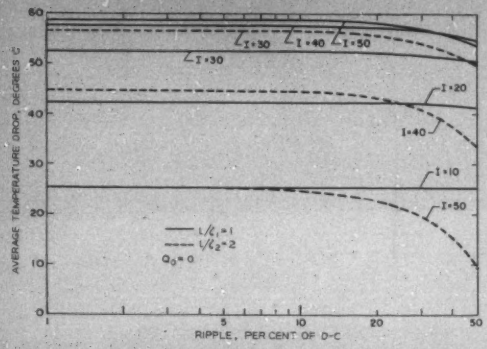


Fig. 7. Average temperature drop as a function of the amount ripple with d-c, zero heat load.

It will be assumed that the ripple consists simply of a sinusoidal wave, so that the total current is of the form

$$i = i_1 + i_2 \sin \omega t \tag{41}$$

Hence

$$= i_1$$

$$^2 = i_1^2 + \frac{i_2^2}{2} \tag{42}$$

The boundary conditions of the problem are:

$$\text{at} \quad x=0, \qquad \bar{T} = T_c \tag{43}$$

$$\text{at} \quad x=l, \qquad -2\zeta\kappa \frac{\partial \bar{T}}{\partial x} + E\,\bar{Q}_0 = 2\zeta\alpha E\, i_1 \tag{44}$$

where

$\bar{Q}_0$ = average heat leakage, watts

Solution of equation 40 with the boundary conditions of equations 43 and 44 gives for the average temperature difference between hot and cold junctions

$$\Delta\bar{T} = T_0 - \bar{T} = \frac{\frac{\alpha}{\kappa_1} EI_1 T_0 \frac{l}{\zeta} - \frac{Er}{2\kappa}\left(I_1^2 + \frac{I_2^2}{2}\right)\frac{l^2}{\zeta^2} - \frac{l}{2\zeta\kappa}\bar{Q}_0}{1 + \frac{\alpha}{\kappa} EI_1 \frac{l}{\zeta}} \tag{45}$$

It is to be noted that the effect of the ripple on the temperature difference comes through the Joule heat only, since the average Peltier cooling is unaffected by the ripple, provided the latter is symmetrical around the d-c component.

Figs. 7 and 8, computed from equation 45, show the average temperature difference as a function of the ripple amplitude in percent of d-c component (i_2/i_1) with the direct current as a parameter, for values of the heat leakage equal to 0 and 1 watt, respectively. The heavy-line curves correspond to a thermoelement length to surface ratio equal to 1 and the dashed-line curves to a ratio equal to 2.

The effect of the ripple is very small if the thermoelement is operated with comparatively low currents, well below the maximum on the increasing branch of the static curve, and this is true even for ripples with peaks close to 50% of the d-c components. In Fig 7 the curve corresponding to $l/\zeta_1 = 1$ and $I = 40$ amperes starts to fall off when the ripple is 20% and the result for $I = 50$ amperes, which is on the decreasing portion of the static characteristic, is even more dependent on the percentage ripple. The dashed-line curves, corresponding to $l/\zeta = 2$, show that the ripple is considerably more adverse for the same currents. Thus, if the operating current is above 30 amperes, a ripple amplitude in excess of 10% of the direct current causes appreciable loss of temperature drop.

The same considerations apply to Fig. 8. Thus, it may be concluded that the use of a thermoelement length to surface ratio l/ζ over unity adds to the smaller maximum temperature drop achievable the additional disadvantage of having to filter the d-c wave more carefully.

CONCLUSIONS

From the steady-state analysis of a p-n junction cooling cell, the difference between hot and cold junction temperature ΔT is strongly dependent on the thermoelement length-to-surface ratio, and the maximum temperature difference achievable is increased considerably by improving the insulation.

When no heat leakage exists, the maximum temperature drop is independent of the thermoelement length-to-surface ratio but the width of the current-dependent curve depends upon the ratio. The larger the ratio the sharper is the curve, which means that even though the maximum is obtained at lower currents, this may turn out to be disadvantageous unless provision is made to stabilize the operating current.

Insofar as the transient analysis is concerned, the thermoelement length-to-surface ratio is found to be also very important in the speed of response. The statement that by keeping the operating current con-

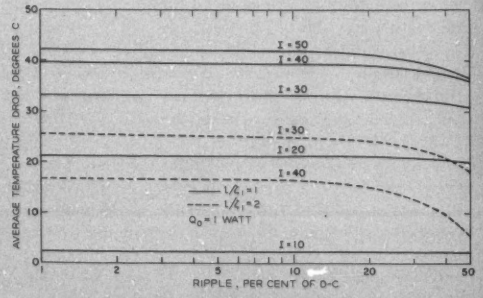


Fig. 8. Temperature drop as a function of ripple assuming 1-watt heat load.

stant, speed is gained when the length is made smaller is not always true, since it depends on whether the operating point is in the increasing or decreasing branch of the static characteristic. When the operating point is in the descending portion of the static curve and very far from the maximum, the system responds rapidly and overshoot may occur. However, in general, if the system is well insulated the aforementioned statement applies.

The study of the refrigerator operated with an incompletely filtered supply shows that the ripple adversely affects the average temperature drop. If the operating point is in the descending branch of the static curve, ripple in excess of 10% may not be tolerable. However, if the operating point is in the increasing branch, ripple as large as 40% may be tolerated provided a good average temperature drop is the feature of interest and true constancy of temperature within the ripple cycle is not sought.

Throughout the analysis it has been assumed that the temperature variation of the thermoelectric power is zero. Work elsewhere has attempted to take into account the temperature variation of α for steady-state cooling. In most cases empirical curves of α versus T can be fitted by either logarithmic or linear functions and used as a starting point to analyze the effect of the Thomson heat. The analysis of the transient response, taking into account the Thomson effect, involves so many mathematical difficulties that a finite-difference method of solution appears the only promising approach.

The transient analysis presented could be further refined by representing the hot junction as fin-cooled, and possibly considering 2-stage couples in cascade. Again the mathematical difficulties become great and analog methods of solution, as in other heat-flow problems, appear desirable.

REFERENCES

1. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. F. Ioffe. Infosearch Ltd., London, England, 1957.

2. Thermoelectric Effects, F. E. Jaumot. *Proceedings*, Institute of Radio Engineers, New York, N. Y., Mar. 1958, p. 538.

3. On The Action of Thermoelectric Cooling Cells Under Non-Stationary Conditions, L. S. Stilbans, N. A. Fedorovick. *Zhurnal Tekhnicheskoi Fiziki*, Moscow, USSR, vol. 28, 1958, p. 489.

4. Transient and Steady State Theory of Semiconductor Thermoelectric Cooling Cells, Nieves Alfonso. *Ph.D. Thesis*, Carnegie Institute of Technology, Pittsburgh, Pa., Oct. 1959.

Laboratory Specializes in Model Instrumentation

Combining both standard and specially built instruments into test instrumentation units for use in wind tunnel model experiments is the specialized function of this Boeing Airplane Company laboratory located at Wichita, Kans. It is designed, equipped, and staffed to aid the company's aerodynamicists in order that they may obtain the maximum amounts of data for the wind tunnel time expended.

Linked with a model shop, which employs approximately 50 model makers and machine operators, as well as a model design area, the wind tunnel support instrumentation laboratory is responsible for the development, maintenance, checkout, and calibration of instrument systems. These systems are used extensively in the testing of wind tunnel models.

The instrumented models are shipped for testing to one of Boeing's three Seattle, Wash., aerodynamic wind tunnels—transonic, supersonic, and hypersonic—or to other wind tunnels at various points throughout the United States.

Boeing's Wichita Division research facilities also include laboratories and installations for propulsion, structures, electrical and electronics, flight test, and digital computer activities. The division has prime responsibility for the research, design, and development work, in addition to the production of the B-52 platform bomber series. It is anticipated that the latest version, known as the B-52H, will be ready for roll-out during January 1961.

Semiconductor Materials for Thermoelectric Power Generation up to 700 C

F. D. ROSI J. P. DISMUKES E. F. HOCKINGS

An investigation into the thermoelectric properties of semiconductor materials to uncover the feasibility of power-generating efficiencies at temperatures from 25 to 700 C. Discussion is centered on general considerations of efficiency factors leading to materials selection and some preliminary results in the evaluation of compound semiconductors and their solid-solution alloys.

IN RECENT YEARS there has been a rapidly growing interest among solid-state researchers in the problem of the direct conversion of heat to electric energy by thermoelectric means. From a technological viewpoint, perhaps the most important consideration at the present time is to demonstrate the feasibility of power-generating efficiencies competitive with conventional converters. In this connection, the need for a broad materials research program cannot be overemphasized, because material operation over a wide temperature range, and at high temperatures is necessary for high efficiencies. By contrast, this looms as a much more formidable problem than that concerned with thermoelectric cooling, where operating temperature differences are much smaller and material classes are already well-defined. At this early stage of technological development, it would appear that the major advances in thermoelectric power generation will come about largely through a better understanding of transport phenomena in semiconductors, insulators, and semimetals at high temperatures. This is an area of solid-state research which is little understood at present.

This article is concerned with research on semiconductor materials for thermoelectric power generation from 25 to 700 C. This temperature range has significance in that it includes the possible utilization of focused solar and nuclear heat sources. The research will be presented in two parts: (1) general considerations of efficiency factors leading to materials selection, and (2) some preliminary results of recent studies in the evaluation of compound semiconductors and their solid-solution alloys.

GENERAL CONSIDERATIONS

THE APPLICATION of thermoelectricity to power generation makes use of the well-known Seebeck effect which provides a current when the junctions of dissimilar materials forming a thermocouple loop are maintained at different temperatures. Fig. 1 shows a schematic representation of a Seebeck thermocouple with branches consisting of p- and n-type semiconductors joined at their ends by a metallic conductor. Heat is supplied to the hot junction T_h from an external source, and the other junction is maintained at a fixed,

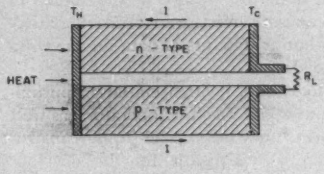


Fig. 1 Thermocouple as power generator.

lower temperature T_c. As a result of the temperature difference $T_h - T_c$, a current I flows in the direction indicated by the arrows through an external load resistance R_L inserted into the circuit between the cold junctions. Hence, the thermocouple arrangement in Fig. 1 represents a direct conversion of heat into electrical energy with a coefficient of performance ϕ given by

$$\phi = \frac{\text{power supplied to load}}{\text{heat absorbed at hot junction}} \qquad (1)$$

The useful power is simply I^2R_L; and if the Thomson heat is neglected, the heat absorbed at T_h consists of the Peltier heat H_1, and the heat withdrawn from the hot junction by conduction H_2

A special article recommended for publication by the AIEE Solid State Devices Committee.

F. D. Rosi, J. P. Dismukes, and E. F. Hockings are with the Radio Corporation of America, Princeton, N. J.

The authors are deeply indebted to R. L. Novak for permission to present some of his unpublished data on the InAs-GaAs alloys. They also wish to express their gratitude to W. Mularz, H. Berman, and R. V. Jensen for their assistance in carrying out various phases of the experimental program, and to W. C. Roth for the X-ray analyses. Recognition is also due to G. D. Cody and B. Abeles for helpful discussions during the course of the work.

The research reported in this article has been sponsored by the U. S. Navy, Bureau of Ships, under Contract No. NOBS 77057.

$$H_1 = Q\,I\,T_h \tag{2}$$

and

$$H_2 = K\,(T_h - T_c) - 1/2\,I^2R, \tag{3}$$

where

Q = thermoelectric power or Seebeck coefficient of junction
K = thermal conductance of the two branches in parallel
R = sum of branch resistances

The coefficient of performance is then given by

$$\phi = \frac{I^2\,R_L}{Q\,I\,T_h + K\,(T_h - T_c) - 1/2\,I^2R}; \tag{4}$$

and under optimum load (R_L) conditions the expression for maximum efficiency is

$$\phi_{max} = \frac{T_h - T_c}{T_h}\,\frac{\sqrt{1 + z\,\overline{T}} - 1}{\sqrt{1 + z\,\overline{T}} + T_c/T_h}, \tag{5}$$

where

$$\overline{T} = (T_h + T_c)/2$$

and

$$z = Q^2/RK \tag{6}$$

The quantity z is commonly referred to as the "figure of merit" of the thermocouple[1]; and if the resistances of the branches are matched to give z a maximum value, then the figure of merit z becomes a function only of material constants of the two branches

$$z = \frac{(Q_a - Q_b)^2}{(\sqrt{\rho_a\kappa_a} + \sqrt{\rho_b\kappa_b})^2} \tag{7}$$

Here Q_a and Q_b, ρ_a and ρ_b, and κ_a and κ_b are the Seebeck coefficients, electrical resistivities, and thermal conductivities of the two branches, respectively. For the case where

$$Q_a = -Q_b$$

and

$$\rho_a\,\kappa_a = \rho_b\,\kappa_b$$

$$z = z_a = Q_a^2/\rho_a\,\kappa_a \tag{8}$$

Here the figure of merit is defined in terms of the material constants of a single branch of the thermocouple.

It may be seen from equation 7 that the properties of primary importance in the evaluation of materials for thermoelectric power generation are the same as those for refrigeration. From equation 5 it is further apparent that for optimum power generating efficiency, it is desirable to maximize the factor, $z\overline{T}$; i.e., to obtain as high a value of z over as wide a temperature range as possible. This places on the semiconductor the additional requirements of a large energy band gap and high melting point. A larger band gap is desirable, since it permits operation of the thermocouple at higher hot-junction temperatures without a prohibitive loss in thermoelectric properties. This follows from the knowledge that an increase in the band gap of a semiconductor shifts the onset of intrinsic conduction due to thermal generation of electron-hole pairs to higher temperatures; and such electron-hole pair generation must be avoided, since it results not only in a marked decrease in the thermoelectric power, but also an increase in thermal conductivity due to the diffusion of the electron-hole pairs from $T_h \rightarrow T_c$.

The need for a higher melting point and corresponding chemical stability is obvious, and usually accompanies a larger energy band gap. Unfortunately, the higher the melting point T_m of a material, the larger is its Debye characteristic temperature θ and, hence, lattice thermal conductivity κ_{ph} at a given temperature.[2] This may be seen from the expression derived by Leibfried and Schlömann[3]

$$\kappa_{ph} = \frac{\theta^3}{\gamma^2}\,[M\,V^{1/3}\,(\theta/T)]\,C \tag{9}$$

Here M and V are the atomic weight and volume of the material, respectively; and $\gamma = \delta \ln \Theta / \delta \ln V$, and C is a numerical constant. Equation 9 holds for the case where phonon-phonon interactions are the main source of thermal resistance, which is the usual situation at elevated temperatures. Since θ is proportional[2] to $(T_m/M)^{1/2}$, then it follows from equation 9 that κ_{ph} is proportional to $(T_m^3/M)^{1/2}$. Fig. 2 shows a plot of κ_{ph} at 300 K vs. $(T_m^3/M)^{1/2}$ for both elemental and III–V compound semiconductors having the diamond-cubic structure. The linearity and parallel nature of the curves would indicate the validity of such plots.

From the foregoing considerations, one could reasonably conclude that there is an upper temperature limit to the usefulness of semiconductors exhibiting semiconductor behavior at room temperature for thermoelectric power generation. From available data on κ_{ph} in semiconductors, and the degree to which κ_{ph} can be decreased by solid-solution alloying, it was concluded that semiconductors would be most useful in power-generating thermocouples at least up to 700 C.

MATERIALS RESEARCH

In the research on semiconductor materials for thermoelectric power generation, it became apparent from the beginning that no one material could provide the desired figure of merit for high efficiencies over the temperature range of interest, 25 to 700 C. Consequently, attention was directed to a consideration of thermocouple branches constructed in a sandwich-type arrangement, where materials are selected to provide a high average figure of merit z over relatively narrow temperature ranges. This arrangement is illustrated by the schematic diagrams of Fig. 3, which show the temperature dependence of the z values for materials, *A*, *B*, and *C*, and their arrangement in the branch of a thermocouple. It is apparent from the temperature dependence of z that material *A* provides the best average z value in the range 25 to 300 C; *B* provides the best average z value in the range 300 to 500 C; and so on. Thus, by placing these materials in the series arrangement shown in the upper diagram of Fig. 3, one obtains

an envelope of z vs. T curves (indicated by the heavy lines in Fig. 3) which represents the best average z value over the entire operating temperature range $T_c \rightarrow T_h$ of the thermocouple. With this principle of thermocouple construction in mind, some preliminary data will now be presented on the evaluation of semiconductor materials for power generation over specific temperature ranges.

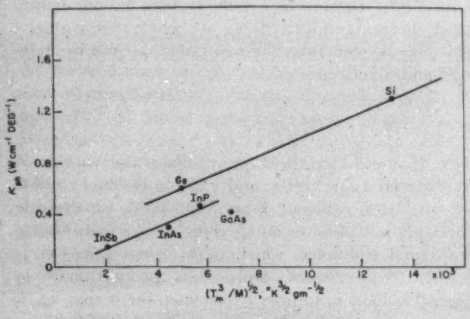


Fig. 2 K_{ph} at 300 k vs. $(T^3_m/M)^{1/2}$ for semiconductors.

The data on the thermal and electrical properties of the materials were obtained in the following manner: The electrical resistivity ρ was determined by an a-c scanning method; the thermoelectric power Q and thermal conductivity κ were measured simultaneously by the standard technique of establishing a small temperature gradient across the specimen placed between a heater and sink; and the carrier concentration n and mobility μ were obtained from measurements of Hall constant. The lattice contribution to the thermal conductivity κ_{ph} was obtained from the measured total thermal conductivity κ from the simple relation

$$\kappa = \kappa_{ph} + \kappa_{el},$$

where the electronic contribution κ_{el} was calculated from the Wiedemann-Franz relation

$$\kappa_{el} = S\,(k/e)\,T/\rho$$

Here $S = \pi^2/3$ for nondegeneracy and lattice scattering of carriers, and $S = 2$ for degeneracy and impurity scattering.

Bi_2Te_3 Alloys. In the course of research on materials for thermoelectric cooling[4], it became apparent that solid-solution alloys of Bi_2Te_3 with other compound semiconductors could also be useful in power generating thermocouples operating with hot-junction temperatures as high as 350 C. Consequently, a power generating thermocouple similar to the arrangement shown in Fig. 1 was constructed from n- and p-type semiconductor alloys having the following composition: (a) n-type, Bi_2Te_3–25% Bi_2Se_3; and (b) p-type, Bi_2Te_3–40% Sb_2Te_3–10% Sb_2Se_3.

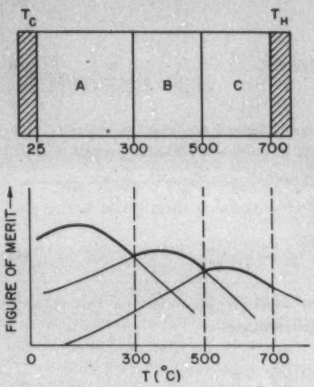


Fig. 3 Principle of sandwich arrangement of materials A, B, and C along branch of power-generating thermocouple.

The n-type material was doped with CuBr, and the p-type material with excess Bi. The alloy composition of these semiconductors was adjusted so as to give a lattice thermal conductivity κ_{ph} lower than that of Bi_2Te_3 and an energy band gap ΔE larger than that of Bi_2Te_3, as may be seen from the comparative data in Table I. These requirements are consistent with the general considerations discussed in the previous section.

Table I. Comparison of Lattice Thermal Conductivity, κ_{ph}, and Energy Band Gap ΔE between Bi_2Te_3 and the Alloy Semiconductors Used in Power Generating Thermocouple.

Semiconductor	κ_{ph} (Watts cm^{-1} deg^{-1})	ΔE (ev)
Bi_2Te_3	0.013 (4)	0.15 (18)
Bi_2Te_3 – 25 % Bi_2Se_3	0.009 (4)	0.28 (18)
Bi_2Te_3 – 40 % Sb_2Te_3 – 10 % Sb_2Se_3	0.006 (4)	0.20*

*Estimated from measurements of thermoelectric power as a function of electrical conductivity at room temperature.

Table II gives the thermoelectric properties of these alloys at room temperature. The electrical resistivity ρ of each alloy was adjusted to provide not the highest value of z at room temperature (z values as high as 2.8 x 10^{-3} per degree have been obtained at 300 K with these materials), but instead the best average value of z over the temperature range of operation of the thermocouple (25 to 325 C).

Table II. Room Temperature Properties of Semiconductor Branches of Power Generating Thermocouple.

Thermocouple Branch Material	Conductivity Type	Impurity Added	Q (μv deg^{-1})	ρ (ohm-cm)	κ (Watts cm^{-1} deg^{-1})
Bi_2Te_3 – 25 % Bi_2Se_3	n	CuBr	150	6×10^{-4}	0.020
Bi_2Te_3 – 40 % Sb_2Te_3 – 10 % Sb_2Se_3	p	Bi	155	8×10^{-4}	0.015

In the construction of the thermocouple from the alloys in Table II, the metal-semiconductor junctions were made by direct soldering with a Bi–20% Sb alloy.

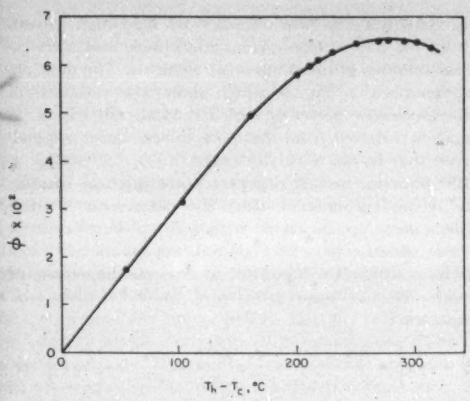


Fig. 4 Variation of power generating efficiency ϕ with temperature range of operation. $T_c = 25$ C.

Heat was supplied to the hot-junction by a wire-wound, resistance heater; and the cold-junction temperature was fixed at 25 C by circulating water. The variation in power generating efficiency (watts output/watts input) with temperature difference $T_h - T_c$ along the thermocouple branches is shown in Fig. 4. It may be seen from the curve that a maximum efficiency of approximately 6.5% is obtained while operating over a temperature difference of 300 C from $T_c = 25$ C to $T_h = 325$ C. From such efficiency measurements as a function of temperature, it was possible to calculate the temperature variation of the average figure of merit z for the n- and p-type alloys. These data are shown in Fig. 5, from which it may be seen that the value of z decreases continuously with increasing temperature of thermocouple operation, and that over the temperature range 25 to 250 C, an average z value of approximately 1.7×10^{-3} per degree is realized.

In connection with the efficiency data in Fig. 4, it should be noted that measurements on the variation of thermoelectric properties with temperature of both the n- and p-type alloys indicated that the p-type branch was not operating as efficiently as the n-type branch. In addition, metallographic examinations showed that the soldered junctions were beginning to break down at $T_h = 325$ C. These observations strongly suggest that with a slight improvement in the metal-semiconductor junction as well as a better adjustment of the electrical conductivity of the p-type branch, it should be possible to obtain a power-generating efficiency up to 10% with these semiconductor alloys while operating over a temperature range of 300 C. Equally important, with the same general family of compounds, the figure of merit of p-type alloys has very recently been increased considerably from the previous optimum value of 2.8×10^{-3} per degree.

Ternary Compounds. Exploratory research on the thermoelectric properties of ternary compounds has shown that this new class of materials includes semiconductors that could be useful for power generation at intermediate temperatures. This work was initially concerned with compounds having a cubic structure, and in this crystallographic system there are three general types: the rock salt, zinc blende, and fluorite. Ternary compounds of all three types have been prepared, and some of their thermoelectric properties determined. The data are summarized in Table III. Of particular interest is the observation that the rock salt structure has been found for $AgSbS_2$, $AgSbSe_2$, $AgSbTe_2$, $AgBiS_2$ and $AgBiSe_2$; and all of these compounds are characterized by low lattice thermal conductivities (< 0.0075 watt per centimeter per degree). However, when the Group V element in these compounds is replaced by a Group III element, the resulting compounds have basically the zinc blende structure. This differs from the rock salt structure in that each atom has only four nearest neighbors arranged tetrahedrally, as against six neighbors arranged octahedrally for the rock salt structure. This reduction in co-ordination number is associated with an increase in thermal conductivity, as may be seen from the data in Table III.

1. *$AgSbTe_2$.* Of the ternary compounds examined to date, $AgSbTe_2$ was found to be the most promising for thermoelectric power generation, since it has a low lattice thermal conductivity (0.0063 watt per centimeter per degree)[5], an estimated band gap > 0.2 ev (electron volts), a reasonably high thermoelectric power (> 200 microvolts per degree), and a correspondingly low elec-

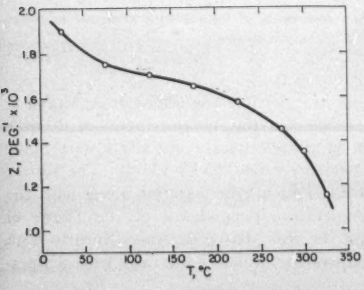


Fig. 5 (*left*) Temperature dependence of average figure of merit z for n-type Bi_2Te_3 – 25% Bi_2Se_3; and p-type Bi_2Te_3–40% Sb_2Te_3 – 10% Sb_2Se_3 alloys.

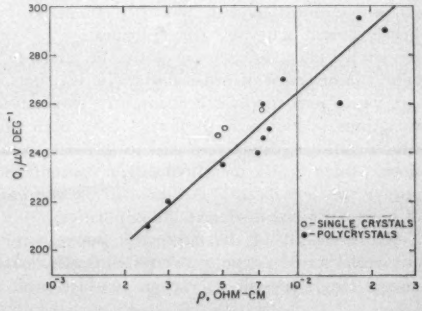


Fig. 6 (*right*) Dependence of thermoelectric power Q on resistivity ρ in p-type $AgSbTe_2$ at 300 K.

trical resistivity (10^{-3} ohm-cm). Hence, this compound will be discussed in some detail.

Table III. Properties of Ternary Compounds.

Structure	Composition	Lattice Parameter (Å)	Resistivity (ohm-cm)	Thermoelectric Power ($\mu v\ deg^{-1}$)	k_{ph} (Watts $deg^{-1}\ cm^{-1}$)	General Remarks
Cubic-Rock Salt	$AgSbS_2$	5.658	5.3×10^{4}	—	0.0049	Transitions at 252 and 382C. m.pt. 523C
	$AgSbSe_2$	5.792	36	+300	0.0075	m.pt. 657C
	$AgSbTe_2$	6.076	5×10^{-3}	+220	0.0063	m.pt. 570C
	$AgBiS_2$	5.646	5×10^{2}	—	—	m.pt. 812C
	AgBiSe		5×10^{-3}	+ 98	0.0073	Transition at 306C, m.pt. 766C
Cubic-Zinc Blende and Related structures	$CuGaSe_2$	tetragona				
	$CuGaTe_2$	6.017	4×10^{-3}	+100	0.064	
	$CuInSe_2$	tetragona	4	—	0.037	
	$CuInTe_2$		2×10^{-3}	+160	0.049	
	$AgGaSe_2$	tetragonal	—	—	—	
	$AgGaTe_2$		14	+380	0.0095	
	$AgInSe_2$	tetragonal	—	—	—	
	$AgInTe_2$	tetragonal	2	+100	0.012	
	$AgCrSe_2$	rhombohedral	0.5	—	—	m.pt. 1000C
	$AgCrTe_2$	—	$8\times10^{-}$	8	—	Structure not ully interpreted
	$CuFeSe_2$	—	18	—	0.065	
	$AgFeTe_2$	—	7×10^{-4}	− 76	0.02	$n=1.5\times10^{18}\ cm^{-3}$ $\mu=6{,}600\ cm^2\ v^{-1}\ sec^{-1}$
Cubic-Fluorite	CuZnAs	5.905	2.8×10^{-4}	8		
	NiZnSb	5.905	3.9×10^{-5}	2.6		Metallic conduction
	NiMgSb	—	1.6×10^{-4}	−6		
Complex	$CuAsSe_2$	—	1.0×10^{-3}	4	0.032	
	$CuSbS_2$	—	2×10^{2}	—	0.015	
	$CuBiS_2$	—	41	—	0.0051	
	$AgAsSe_2$	—	6×10^{4}	—	0.0045	m.pt. 394C

The main deterrent to the proper evaluation and ultimate utilization of $AgSbTe_2$ as a power-generating material is the present inability to adjust its electrical properties through controlled impurity additions. For example, it has not yet been possible to obtain: (1) p-type material with resistivities below 2×10^{-3} ohm-cm; and (2) n-type material. Attempts to obtain these electrical characteristics have failed in spite of a large number of experiments with both elemental and compound doping, which included additions of Cr, Cu, Si, Pb, Sn, Fe, SbI_3, CdI_3 and excess Ag, Sb, and Te. Although in no case was n-type conductivity observed, some of the impurities did bring about an increase in the p-type resistivity, which could indicate impurity compensation and, hence, donor behavior. Zone purification of $AgSbTe_2$ has shown effective removal of Cu, Fe, and Mg. However, the behavior of other impurities was not consistent, which may simply reflect impurity interactions. No variations in electrical properties have been observed which could be directly related to impurity concentrations. Moreover, the measured carrier concentration has always been significantly greater than the concentration of spectrographically detectable impurities.

Measurements of thermoelectric power were made on a number of p-type, polycrystalline specimens, and several single crystals of various conductivities at 300 K. This material was obtained by Bridgman growth from the melt under various conditions, and with excess amounts of the component elements. The data are summarized in Fig. 6, which shows the variation of thermoelectric power Q with electrical resistivity ρ. It may be inferred from the more or less linear dependence that in the resistivity range, 2.5×10^{-3} to 2.3×10^{-2} ohm-cm, neither degeneracy nor intrinsic conductivity are encountered, since the occurrence of these phenomena are associated with a sharp decrease in Q. From measurements of Hall constant on the low-resistivity samples, it was possible to estimate the density of states effective mass ratio $m^{(N)}$ for holes from the equation[6]

$$Q = 86.2\left[\ln\frac{4.70\times10^{15}}{n_h} + \frac{3}{2}\ln\frac{m^{(N)}}{m} + \frac{|\Delta\varepsilon_T|}{kT} + \frac{3}{2}\ln T\right] \quad (10)$$

Q = microvolts per degree
n_h = concentration of holes
$|\Delta\varepsilon_T|/kT$ = kinetic energy term
T = absolute temperature

On assuming a value of $|\Delta\varepsilon|/kT$ of 3.2 for impurity scattering[6], the value of m^N/m for holes in $AgSbTe_2$ was calculated to be 0.36. If on the other hand a value of 1.7 is taken for the kinetic energy term corresponding to a predominantly lattice scattering, the value of $m^{(N)}/m$ is 0.88. This large density of states effective mass ratio for holes is probably the main reason for the high promise of $AgSbTe_2$ as a power-generating material, in addition to its relatively large value of hole mobility estimated to be 200 to 300 cm^2 per volt per second.

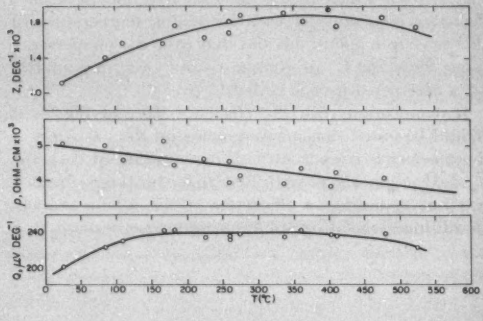


Fig. 7 Temperature dependence of thermoelectric properties in p-type $AgSbTe_2$.

To determine the possible usefulness of $AgSbTe_2$ as a power generating material, measurements of thermoelectric power Q and electrical resistivity ρ were made over the temperature range, 25 to 525 C.. The results are shown in Fig. 7 for p-type material, along with the calculated temperature dependence of the figure of merit z. It may be seen that ρ decreases linearly with increasing temperature, while Q increases with temper-

ature and exhibits a broad maximum which is not usually observed, but desirable. The decrease in ρ would seem to be due to an anomalous increase in the mobility of holes with temperature. The fact that Q does not decrease sharply at the high temperatures suggests that intrinsic conduction due to thermal generation of electron-hole pairs is not encountered in this material even at 525 C. The temperature dependence of z in Fig. 7 was determined from the expression, $z = Q^2/\rho\kappa$. Here the total thermal conductivity, $\kappa = \kappa_{el} + \kappa_{ph}$, at any given temperature was estimated by calculating the electronic contribution κ_{el} from the measured value of ρ, and by assuming the room temperature value of the lattice contribution κ_{ph} (0.0063 watt per centimeter per degree) to be invariant with temperature. The latter assumption represents a conservative approach toward estimating the temperature dependence of z, since in general κ_{ph} varies as T^{-1} in crystalline solids. No account was taken of a possible ambipolar contribution to the total thermal conductivity, which is reasonable in view of the Q values at the high temperatures. It may be seen from Fig. 7 that the broad maximum in Q is also manifested in the temperature dependence of z; and it is noteworthy that an average z value of approximately 1.6×10^{-3} per degree is obtained in this p-type compound over the temperature range 100 to 500 C.

Fig. 8 shows the combined variation of the figure of merit with temperature for the $(Bi, Sb)_2$ $(Te, Se)_3$ alloys and p-type $AgSbTe_2$. In the case of the former, the z dependence represents the average for the p- and n-type materials (see Table II). It may be seen that construction of a p-type branch of a thermocouple from these materials could provide an average z value of $\sim 1.75 \times 10^{-3}$ per degree over the temperature range, 25 to 525 C. This would require operation of the $(Bi,Sb)_2$ $(Te, Se)_3$ alloy from 25 to 175 C and the $AgSbTe_2$ from 175 C to 525 C, as indicated by the heavy-lined envelope of curves in Fig. 8. It is noteworthy that if an n-type material could be found with a temperature dependence of z similar to the p-type $AgSbTe_2$, a power generating efficiency of 14% is possible with these materials over a $T_h - T_c = 500$ C.

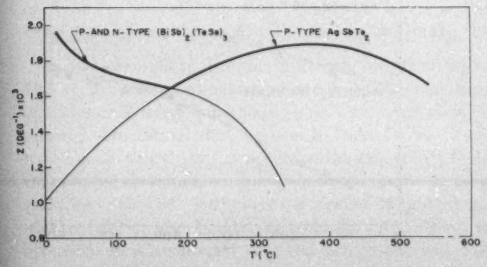


Fig. 8 Variation of figure of merit z with temperature for promising thermoelectric materials.

2. *$AgSbTe_2$ Alloys.* It has been shown[4, 8, 9, 10] that solid-solution alloying of semiconductors can be desirable for thermoelectric applications for the following reasons: (1) it can improve the figure of merit by decreasing the lattice thermal conductivity without, at the same time, greatly decreasing the Q^2/ρ ratio; and (2) it enables one to adjust in a controlled manner such important physical properties as energy band gap. Consequently, solid-solution alloys of $AgSbTe_2$ with the IV –VI compounds, PbTe, SnTe, and GeTe, were examined. These alloy systems were selected, because earlier work on their phase diagrams indicated complete solid miscibility. In the present article, data will be presented only on the AgSbTe–GeTe alloys as a prototype of these systems. This will include the phase equilibrium diagram for this system, the dependence of thermal conductivity on alloying at 300 K, and the variation of Q, ρ, and z on temperature for selected alloys. One point of interest in connection with the $AgSbTe_2$–PbTe system, however, should be mentioned here. In the variation of lattice conductivity with alloying at 300 K, a broad minimum in the curve was obtained corresponding to a κ_{ph} of 0.0045 watt per centimeter per degree, which is the lowest value obtained to date in solid-solution alloys of compound semiconductors.

Fig. 9 shows the tentative phase diagram for the $AgSbTe_2$–GeTe system on the basis of differential thermal analysis. Although more data are required for a complete definition of the solidus curve, there is a definite indication of complete solid miscibility. This is further supported by the lattice parameter data shown in Fig. 10, which also shows that the transition in structure from the f.c.c. $AgSbTe_2$ to the rhombohedral GeTe occurs between the compositions, $AgSbTe_2$–75% GeTe and $AgSbTe_2$–90% GeTe.

Data on thermal and electrical properties of some $AgSbTe_2$–GeTe alloys at 300 C, in addition to pure GeTe, are given in Table IV. Again the lattice contribution to the thermal conductivity κ_{ph} was obtained from the measured total thermal conductivity κ from the simple relation: $\kappa_{ph} = \kappa - \kappa_{el}$, assuming nondegeneracy and lattice scattering of carriers for alloys up to $AgSbTe_2$–50% GeTe, and degeneracy and impurity scattering for the alloys with GeTe content above 75%. The values of Q in Table IV were used as a guide to indicate degeneracy.

The general dependence of κ_{ph} on alloying in the $AgSbTe_2$–GeTe system is shown in Fig. 11, where it may be seen that κ_{ph} increases monotonically with increasing GeTe content. The absence of a minimum in κ_{ph}, which is commonly observed in solid-solution alloy systems,[4, 11] would suggest that the lattice strains due to alloying in the $AgSbTe_2$–GeTe system are of too small a magnitude to decrease the already low κ_{ph} of pure $AgSbTe_2$ (0.0063 watts per centimeter per degree). This is not too surprising, since this value of κ_{ph} is already associated with a phonon mean free path of unit-cell dimensions. A dependence of κ_{ph} on alloying, similar to that

shown in Fig. 11, was also observed in the $AgSbTe_2$–SnTe system.

Electrical resistivity and thermoelectric power measurements were made on a selected number of p-type $AgSbTe_2$–GeTe alloys and pure GeTe from 25 C up to 600 C. The results are summarized in Figs. 12 and 13. It may be seen from the curves in Fig. 12 that ρ initially increases with temperature for all the materials, and this can be attributed to a decrease in hole mobility with increasing temperature. Moreover, it appears that the maximum in resistivity is shifted to higher temperatures with increasing GeTe content in the alloys; and in pure GeTe the maximum was not observed even at 600 C. From the curves in Fig. 13, it is apparent that the thermoelectric power Q dependence on temperature is similar to that for ρ, in that it also increases with temperature and reaches a maximum value which is shifted to higher temperatures with increasing amounts of GeTe. These data strongly suggest that the onset of intrinsic conductivity in these alloys occurs at higher temperatures with increasing GeTe content in the alloys; and hence, the band gap increases with alloying in a similar fashion.

To determine the possible usefulness of the $AgSbTe_2$–GeTe alloys as power generating materials, the temperature dependence of the figure of merit ($z = Q^2/\rho\kappa$) for the various p-type alloys was calculated; and these results are summarized in Fig. 14. For purposes of comparison, the data for pure, p-type GeTe is also included.

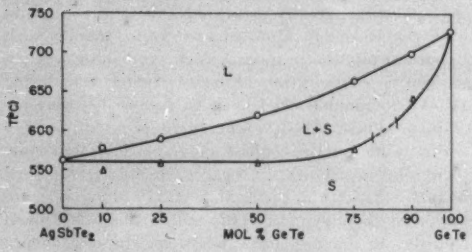


Fig. 9 Phase diagram of $AgSbTe_2$–GeTe system.

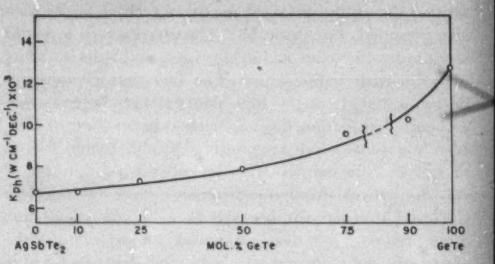


Fig. 11 Variation of lattice thermal conductivity, κ_{ph}, with alloying in $AgSbTe_2$–GeTe system.

It is important to note here that in calculating z over the temperature range indicated in Fig. 14, the total thermal conductivity κ was obtained (1) by calculating κ_{el} from the measured values of ρ, and (2) by assuming a T^{-1} dependence for κ_{ph} with a lower limiting value of 0.0063 watt per centimeter per degree corresponding to the κ_{ph} of $AgSbTe_2$. Such an assumption was considered reasonable in view of some preliminary measurements of κ_{ph} with temperature in one of the alloys.

It may be seen from the temperature dependence of z in Fig. 14 that the $AgSbTe_2$–90% GeTe alloy appears to be the most promising for thermoelectric power generation in the temperature range, 250 to 550 C, where an average z value of $\sim 1.4 \times 10^{-3}$ per degree is obtained. Although this does not represent an improvement over the average z value for pure $AgSbTe_2$ over

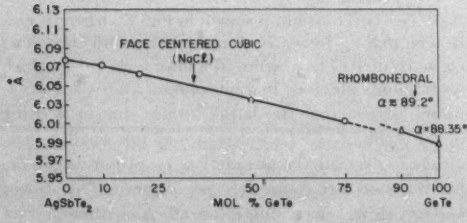


Fig. 10 Lattice parameters of $AgSbTe_2$–GeTe system.

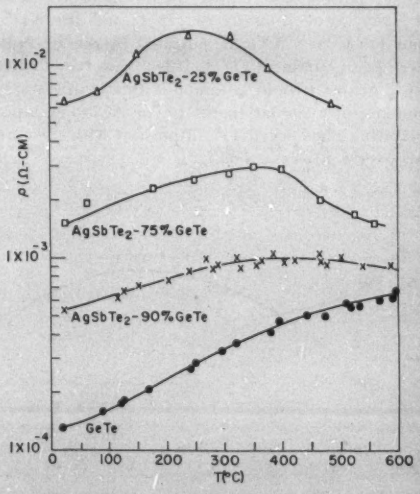


Fig. 12 Variation of resistivity with temperature for p-type $AgSbTe_2$–GeTe alloys.

the same temperature range (see Fig. 7), it should be noted that the thermoelectric data on the $AgSbTe_2$–90% GeTe alloy is of a preliminary nature. Hence, considerable improvements in thermoelectric properties can be expected through (1) improvements in specimen preparation, and (2) better adjustment of electrical conductivity. In addition, it is expected that the useful κ_{ph} by about 70%. A minimum in κ_{ph} of 0.047 watts per centimeter per degree was obtained in this system corresponding to an alloy composition of ~ 50% and a band gap of 0.6 ev.

In the sections to follow, thermoelectric data obtained by R. L. Novak of the RCA Laboratories will be presented on the n-type $In_{0.8}Ga_{0.2}As$ and

Table IV. Thermal and Electrical Properties of $AgSbTe_2$ – GeTe Alloys at 300 K.

Alloy Composition	ρ (ohm-cm)	Q (μv deg^{-1})	K (Watts cm^{-1} deg^{-1})	K_{el} (Watts cm^{-1} deg^{-1})	K_{ph} (Watts cm^{-1} deg^{-1})	n_h (cm^{-3})	μ_h (cm^2 v^{-1} sec^{-1})
$AgSbTe_2$ - 10% GeTe	7.03×10^{-3}	235	0.0069	0.0006	0.0063	4×10^{18}	221
$AgSbTe_2$ - 25% GeTe	5.50×10^{-3}	230	0.0074	0.0008	0.0066	5×10^{18}	230
$AgSbTe_2$ - 50% GeTe	3.30×10^{-3}	212	0.0088	0.0013	0.0075	~ 10^{19}	190
$AgSbTe_2$ - 75% GeTe	1.15×10^{-3}	131	0.0139	0.0048	0.0091	> 10^{19}	—
$AgSbTe_2$ - 90% GeTe	5.25×10^{-4}	70	0.0234	0.0136	0.0098	> 10^{19}	—
GeTe	1.43×10^{-4}	30	0.0687	0.561	0.0122	> 10^{19}	—

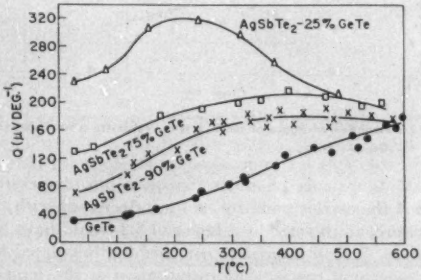


Fig. 13 Variation of thermoelectric power Q with temperature for p-type $AgSbTe_2$–GeTe alloys.

temperature range of the $AgSbTe_2$–90% GeTe alloy will be 50 to 100 C higher than pure $AgSbTe_2$.

One final point of interest in connection with the data in Fig. 14 is the striking improvement in the figure of merit of GeTe over the temperature range, 25 to 550 C, by simply alloying with 10% $AgSbTe_2$. Moreover, the data suggest that above 600 C, pure GeTe is superior to any of the alloys. From this it may be inferred that the band gap of GeTe is higher than that of $AgSbTe_2$ and the alloys—a conclusion which is also supported by the thermoelectric power data in Fig. 13.

InAs–GaAs Alloys. For thermocouple operation up to 700 C, solid-solution alloys of III–V compound semiconductors having band gaps > 0.3 ev were also examined. One such alloy system is InAs–GaAs, which was found to exhibit complete solid miscibility.[12] In this system, therefore, it is possible to obtain, by suitable alloying, materials with melting points ranging from 960 to 1,242 C and band gaps from 0.35 to 1.35 ev. In addition, it was shown[12] that the lattice thermal conductivity of both InAs and GaAs is reduced considerably by alloying, such that a 10% addition of either constituent into the respective pure compound lowers $In_{0.4}Ga_{0.6}As$ alloys, which preliminary results indicated to be the most promising for power generation and which have energy band gaps of 0.45 ev and 0.7 ev, respectively.[12] The alloys were prepared by directly reacting the constituent elements in a graphite crucible, which was contained in an evacuated quartz tube. The reaction took place at 50 C above the melting point of the alloy, and an arsenic vapor pressure of about 1 atmosphere above the melt was maintained by an after heater at 600 C. The alloys were grown at a rate of 1 inch per day by the zone-leveling technique,[13] which limited composition variations to no more than 4% even for the alloy compositions with $x \approx 0.5$. The resulting ingots were polycrystalline with coarse grains elongated in the direction of growth and no evidence of porosity. All undoped material was n-type, and selenium was used as a donor impurity to vary the resistivity of the alloys.

The variation of thermoelectric power with electrical resistivity at 300 K for the n-type $In_{0.4}Ga_{0.6}As$ alloy is shown in Fig. 15. For comparison, data are also included for the compounds InAs and GaAs. It may be seen that for a given ρ, the InAs has a higher value of

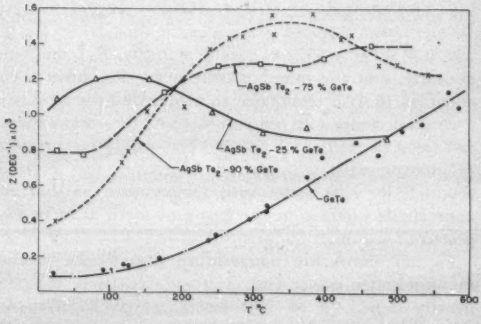


Fig. 14 Variation of figure of merit z with temperature for p-type $AgSbTe_2$–GeTe alloys.

Q than either GaAs or the alloy. This simply reflects the much larger electron mobility of InAs at 300 K for a given carrier concentration.

In Fig. 16, the figure of merit is plotted against ρ at 300 K for InAs, GaAs, and the $In_{0.4}Ga_{0.6}As$ alloy. The maximum figure of merit obtained for the alloy is 2.5 $\times$ 10^{-4} per degree, as compared to values of 1.0 $\times$ 10^{-4} per degree and 0.3 $\times$ 10^{-4} per degree for InAs and GaAs, respectively. This improvement in the z value for the alloy is simply a manifestation of the large decrease in the lattice thermal conductivity due to solid solution alloying strains in this system.[12] However, this maximum value of z for the $In_{0.4}Ga_{0.6}As$ alloy at room temperature is quite low compared to that of other materials. However, at higher temperatures some improvement in z can be expected. The optimized figure of merit of a semiconductor can be expressed as[14]

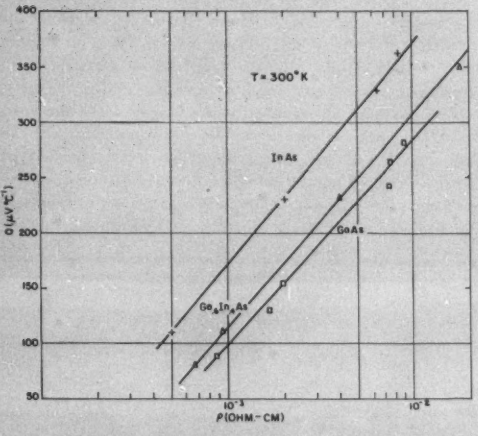


Fig. 15 Variation of thermoelectric power Q with resistivity ρ for InAs, GaAs, and $In_{0.4}Ga_{0.6}As$ alloy.

$$z = 1.16 \times 10^{-7} [\exp A - 2)] (m^N/m)^{3/2} (T/T_0)^{3/2} \mu/\kappa, \qquad (11)$$

where $A = |\Delta\varepsilon_T|/kT$ and μ is the mobility, T_0 room temperature, and the other quantities are the same as in equation 10. It is reasonable to expect that the mobility μ would decrease with temperature as $T^{-3/2}$, or at a lesser rate; and therefore, the factor $\mu T^{3/2}$ would be constant or increase with temperature. Moreover, the thermal conductivity κ decreases with temperature, so that an appreciable increase in the figure of merit is to be expected at the high temperatures.

Fig. 17 shows the temperature dependence of the thermoelectric power and electrical resistivity for two heavily doped ($n \approx 10^{18}$ cm^{-3}), n-type $In_{0.4}Ga_{0.6}As$ alloys in the range 25 to 650 C. It may be seen that Q increases approximately as log T, which indicates that the alloys remain extrinsic over the entire temperature range. The increase in electrical resistivity with temperature is a result of a decrease in electron mobility, since the carrier concentration can be regarded as temperature independent. Fig. 17 also shows the variation of the Q^2/ρ ratio of the alloys with temperature. The maximum values of 2.65 and 2.74 $\times$ 10^{-5} watts per cm per degree^2 occur at 382 and 413 C, respectively. At 400 C

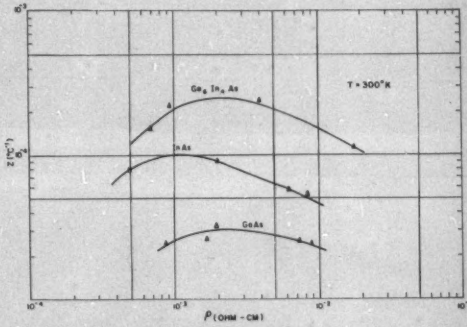


Fig. 16 Variation of figure of merit z with resistivity ρ for InAs, GaAs, and $In_{0.4}Ga_{0.6}As$ alloy.

the Q^2/ρ ratio is 1.8 times that at room temperature; and if the carrier mobility had not decreased with temperature, an increase by a factor of 3.3 would have been realized. It is of interest to compare the calculated with the measured carrier concentrations n at the temperatures for the optimum figure of merit. Using the room temperature data and the theory of Ioffe,[14] one obtains the following

T(°C) of max z	$n_{calc.}$ (cm^{-3})	$n_{meas.}$ (cm^{-3})
382	2.1 $\times$ 10^{18}	1.8 $\times$ 10^{18}
413	2.3 $\times$ 10^{18}	2.4 $\times$ 10^{18}

It is of further interest to note here that on making the reasonable assumption that the thermal conductivity of these alloys above 400 C decreases by a factor of 0.7, one obtains the following estimates of the figure of merit:

T(°C)	z per degree^{-1}
400	0.6 $\times$ 10^{-3}
700	1.0 $\times$ 10^{-3}

These estimates are in general agreement with the expected improvements in z with temperature in accordance with equation 11.

Thermoelectric power and resistivity measurements as a function of temperature up to 700 C were also made on an $In_{0.8}Ga_{0.2}As$ specimen with a room temperature resistivity of 1.37 x 10^{-3} ohm-cm. These data are given in Fig. 18, in addition to the temperature dependence of Q^2/ρ. From the Q and ρ dependence, it may be noted that (1) the specimen goes intrinsic in the vicinity of 400 C and (2) the room temperature value of Q ($\sim$ 175 μv per degree) corresponds to the value for maximum figure of merit. The observation

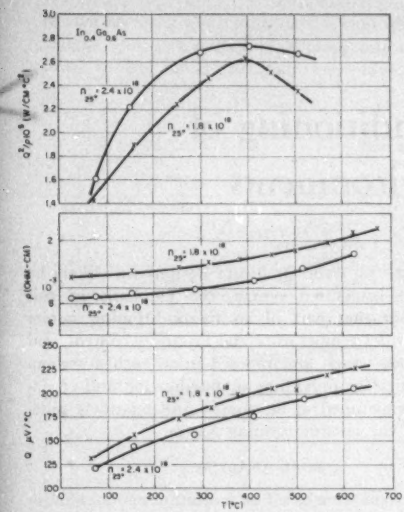


Fig. 17 (*left*) Temperature dependence of thermoelectric properties for two n-type specimens of $In_{0.4}Ga_{0.6}As$ alloys.

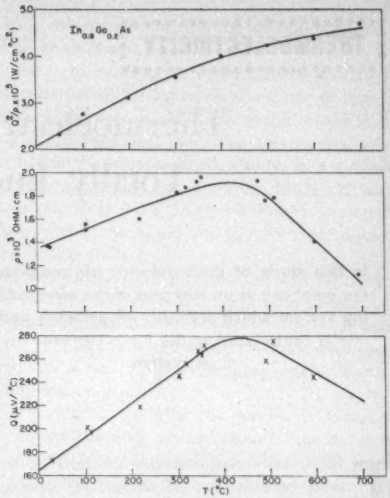


Fig. 18 (*right*) Temperature dependence of thermoelectric properties for n-type $In_{0.9}Ga_{0.1}As$ alloy.

that Q^2/ρ rises continuously with increasing temperature follows from the broadness of Q^2/ρ vs. Q, and the fact that the value of the maximum z is expected to increase with temperature. It is important to note that in the temperature range, 25 to 350 C, where the specimen is still extrinsic, the already high Q^2/ρ values can be increased still further by optimum doping. For example, at 350 C the increase in Q^2/ρ can be effected by simply doping down the value of Q from 265 μv per degree to 175 μv per degree.

To conclude this section on the InAs–GaAs alloys, it should be emphasized that these materials decompose with the evolution of arsenic vapor on heating above 650 C. However, this disadvantage could be overcome by suitable surface treatments.

CONCLUSIONS

A GENERAL CONSIDERATION of the thermoelectric properties of semiconductors suggests that (1) this class of materials can be useful for power-generating thermocouples operating at temperatures at least up to 700 C, and (2) construction of thermocouple branches in a sandwich-type arrangement will be necessary to obtain high figures of merit over a wide temperature range and, hence, high power-generating efficiencies.

Power-generating thermocouples with hot-junction temperatures as high as 325 C can be made with alloys of $(Bi_1Sb)_2$ $(Te_1Se)_3$, and an efficiency of 6.5% has been obtained.

Thermoelectric data as a function of temperature up to 600 C has been obtained on the p-type ternary compound, $AgSbTe_2$, and alloys of this compound with GeTe. The results show that $AgSbTe_2$ and the alloy, $AgSbTe_2$–90% GeTe, are the most promising p-type materials for power generation. An average figure of merit ($Q^2/\rho\,K$) of $\sim 1.75 \times 10^{-3}$ per degree was obtained with $AgSbTe_2$ over the temperature range 175 to 525 C.

Thermoelectric data as a function of temperature up to 700 C have also been obtained for selected n-type InAs–GaAs alloys, which are capable of providing figures of merit up to 1×10^{-3} per degree at a temperature of 700 C.

REFERENCES

1. Poluprovodnikovye Termoelementy (book), A. F. Ioffe. Moscow-Leningrad, USSR, 1956.

2. Heat and Thermodynamics (book), J. K. Roberts, A. R. Miller. New York, N. Y., 1954, p. 552.

3. Gott. Nachr., G. Leibfried, E. Schlomann. IIa, 71, 1954.

4. Materials for Thermoelectric Refrigeration, F. D. Rosi, B. Abeles, R. V. Jensen. *Journal of the Physics and Chemistry of Solids*, Pergamon Press, New York, N. Y. vol. 10, nos. 2/3, July 1959, pp. 191-200.

5. The Thermal Conductivity of Silver Antimony Telluride, E. F. Hockings. *Ibid.* no. 4, Aug. 1959, p. 341.

6. Theory of the Thermoelectric Power of Semiconductors, C. Herring. *Physical Review*, New York, N. Y. vol. 96, no. 5, Dec. 1954, p. 1163.

7. Ambipolar Thermodiffusion of Electrons and Holes in Semiconductors, P. J. Price. *Philosophical Magazine*, vol. 46, ser. 7, 1955, p. 1252.

8. A. F. Ioffe, S. V. Airapetyants, A. V. Ioffe, N. V. Kolomoets, L. S. Stil'bans. Doklady Akademii Nauk. SSSR, vol. 106, no. 6, p. 981, Moscow, USSR, 1956; Translation no. 3, Infosearch Russian Literature Survey, SEMI-1-56, London, England; A. V. Ioffe, A. F. Ioffe. Izvestiya Akademii Nauk. SSSR, Ser. Fiz., vol. 20, no. 1, p. 65, Moscow, USSR, 1956; Infosearch Translation, IA-3-56.

9. Thermal Conductivity and Thermoelectric Power of Germanium-Silicon Alloys, M. C. Steele, F. D. Rosi. *Journal of Applied Physics*, New York, N. Y. vol. 29, no. 11, Nov. 1958, p. 1517.

10. G. N. Gordyakova, G. V. Kokosh, S. S. Sinani. *Zhurnal Tekhnicheskoi Fiziki*, Akad Nauk. SSSR, vol. 28, no. 5, 1958, p. 977.

11. A. F. Ioffe. Proceedings International Conference Electron Transport in Metals and Solids, *Canadian Journal of Physics*, vol. 34, no. 12A, Dec. 1956, p. 1342.

12. Thermal, Electrical and Optical Properties of (In, Ga) As Alloys, M. S. Abrahams, R. Braunstein, F. D. Rosi. *Journal of the Physics and Chemistry of Solids*, vol. 10, nos. 2/3 July 1959, pp. 204-210.

13. Principles of Zone Melting, W. G. Pfann. *Transactions*, American Institute of Mining, Metallurgical and Petroleum Engineers, vol. 194, July 1952, p. 747.

14. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. F. Ioffe. Infosearch, London, England, 1957.

15. I. G. Austin, A. Sheard. *Journal of Electronics and Control*, London, England, III, no. 2, Aug. 1957, p. 236.

Thermoelectric Air Conditioning of Totally Enclosed Environments

G. D. HUDELSON

In this study of thermoelectric air conditioning, the emphasis is on that part of the air-conditioning system which provides temperature and humidity control and on the loads imposed on such a system.

THE totally enclosed environment to be considered here is that of a modern submarine designed for normal operation submerged for long periods of time. Problems encountered in the design of an air-conditioning system for such an application are similar in many respects to those which will confront the designer of environmental control systems for extraterrestrial vehicles. Allowing for differences in magnitude of heat loads, methods of heat rejection to different ambient heat sinks, number of personnel involved, and duration of environmental isolation, the significant similarity remains the absolute isolation and the degree of dependence upon a system which will maintain conditions suitable for human habitability.

The subject of air purification and regeneration is of importance to isolated environments and should logically be considered along with temperature control requirements as an integral part of environmental control system design. For submarine application, true integration of air purification and regeneration systems with air-conditioning systems is desirable but is not yet a reality, because of a number of factors inherent in the development of present-day concepts of submarine design. Air quantities sufficient for adequate ventilation, i.e., removal of objectionable odors and contaminants, oxygen replenishment, and the like, are considerably lower than the air quantities required to absorb internal heat loads and maintain reasonable space temperatures. This factor, along with others, has contributed to the development of two essentially separate systems for maintaining a habitable environment.

A special article recommended by the AIEE Solid State Devices Committee.

G. D. Hudelson is with the Carrier Corporation, Syracuse, N. Y.

The results presented herein were obtained as part of a study performed for the Bureau of Ships, U. S. Navy Department, under Contract No. NObs 77112. Air-conditioning loads presented in Figs. 1, 2, and 3 were obtained from calculations prepared by the Design Division, U. S. Naval Shipyard, Portsmouth, N. H.

The author wishes to acknowledge the work done by G. K. Gable and R. G. Huntington, Carrier Corporation, in conducting the study described.

Although the trend in future designs will likely be toward an integrated system, the emphasis in this article is on that part of an air-conditioning system which provides temperature and humidity control, and on the loads which are imposed upon such a system. The facilities for providing air purification and regeneration are assumed to be present and relatively independent of the air-conditioning system.

LOAD ANALYSIS

DESIGN LOADS were based on minimum and maximum sea-water temperatures of 28 and 85 F, respectively. Air temperatures used for design purposes varied depending upon the space considered. For the purpose in-

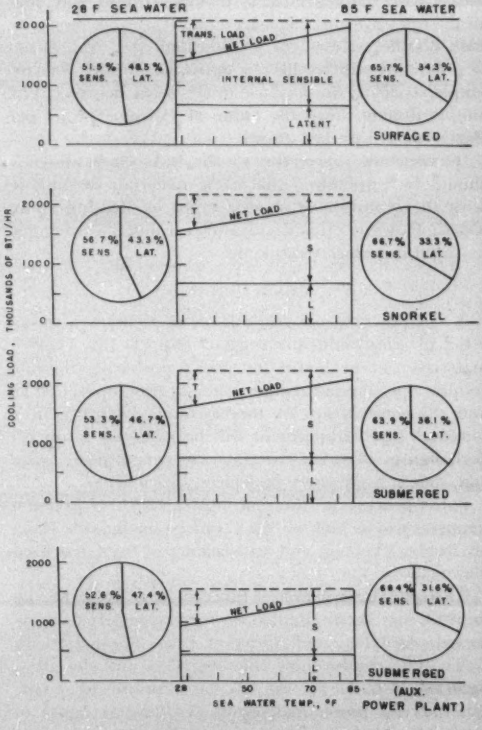


Fig. 1. Load breakdown, entire submarine.

tended here, the space considered is that which includes officers' and crew's sleeping, cooking and eating areas, ship's control center, electronic equipment rooms, and

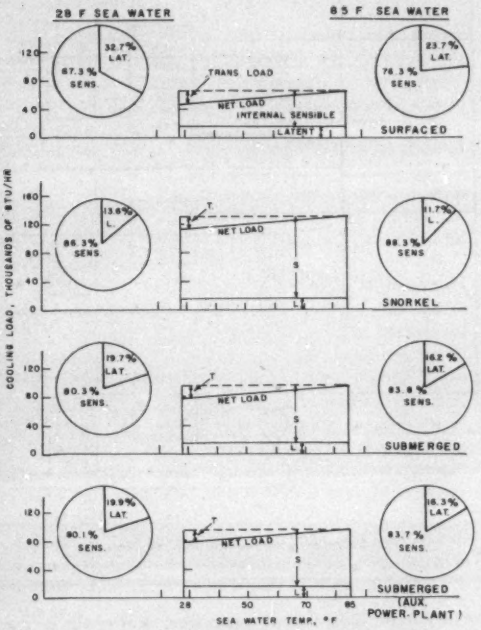


Fig. 2. Load breakdown, forward compartment.

various spaces associated with the ship's operation. Design temperatures in this compartment were 85 F for cooling operation, and 65 F for heating.

The relation between cooling load and sea-water temperature is shown in Figs. 1, 2, and 3. Fig. 1 refers to the entire submarine and includes the auxiliary machinery compartment and the engine room, both high latent-load areas. For convenience in analysis, the forward and amidship compartment has been divided into two subareas as indicated by Figs. 2 and 3.

Although four types of submarine operations are shown, the one of interest here is the submerged condition where isolation from ambient surroundings is complete. Constant internal latent and sensible loads are assumed because of the nature of heat-generating equipment and its relatively constant use factor, with transmission of heat through the hull to the sea water increasing with reductions in sea-water temperature.

It may be observed that all three figures indicate a cooling load requirement over the entire range of sea-water temperatures. Certain areas of the submarine require heat during periods of low sea-water temperature but, in general, internally generated heat loads are of such magnitude that cooling will be required in most areas at all times.

Since the significance of hull transmission is relatively small in the over-all load picture, the range of capacity control necessary for an air-conditioning system is not excessive if internal heat gains can be assumed to remain reasonably constant. Furthermore, it is probable that neither minimum nor maximum loads will occur except for relatively short periods of time, both in terms of the sea-water temperature and the total internal load included in this analysis.

Obviously, some capacity regulation will be needed, but it would appear reasonable to provide a system for air conditioning which would operate at or near maximum efficiency over a range of intermediate load conditions and which would provide full capacity at less than maximum efficiency.

The criterion for judging the merits of a thermoelectric air-conditioning system should thus be its off-design performance characteristics rather than its efficiency or power consumption at design loads. The analysis of the systems described in the following section has been primarily concerned with off-design performance characteristics.

THERMOELECTRIC AIR-CONDITIONING SYSTEMS

System Concepts. A study of the design drawings furnished for the submarine, along with an analysis of intermediate and ultimate heat-rejection methods, led to a number of configurations considered feasible for a

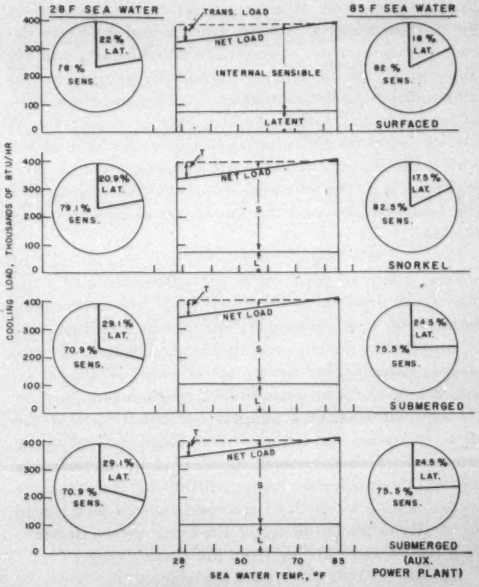


Fig. 3. Load breakdown, amidship compartment.

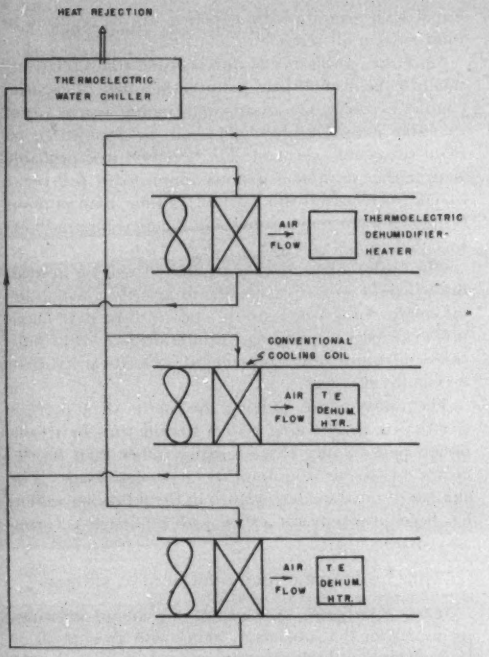


Fig. 4. System with thermoelectric water chiller.

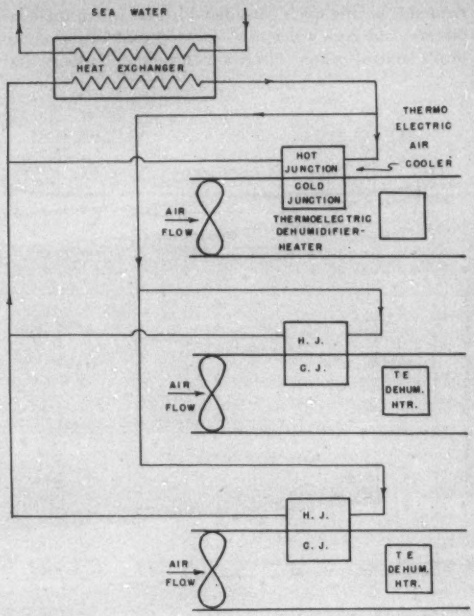


Fig. 5. System with thermoelectric air cooler.

thermoelectric air-conditioning system. Allowing for possible variations of a minor nature, e.g., provisions for reheat, dehumidification control, and auxiliary devices, two basic types of systems emerged from the study. Since in any of the systems considered, the problem of air conditioning the submarine involved the absorption of heat released within the structure by some type of carrier which would ultimately reject the heat to sea water, the significant difference between the two basic systems was in the way heat was to be absorbed within the compartments and the way it was to be rejected to the sea.

Fig. 4 is a schematic representation of one type of system, where air supplied to compartments within the submarine is cooled and dehumidified by conventional finned-tube heat exchangers. Reheat as required may be supplied by electric resistance heaters or by a thermoelectric dehumidifier–heater as indicated in Fig. 4. In this system, the intermediate heat sink is water, flowing through the coils at a temperature below that of the air to be cooled and dehumidified. Heat rejected to the intermediate sink is then transferred by means of a central thermoelectric water chiller to the ultimate sea-water sink, which at design conditions of 85 F would be of the order of 30 to 40 F higher in temperature than the water returning from the cooling coils.

The other type of system considered is shown in Fig. 5. Here, the air-cooling coils are thermoelectric heat pumps, transferring heat from warm air to an intermediate sink at higher temperature, which in turn rejects the heat to sea water by means of conventional heat exchangers. In this system, the intermediate sink water temperature will be of the order of 10 to 20 F higher than the design sea-water temperature.

An obvious alternate system is suggested by the two systems shown in Figs. 4 and 5, i.e., a system utilizing thermoelectric heat pumping devices both as air coolers and for rejection to the sea water. At first inspection, it would appear that some benefit might be gained by thus effectively staging the thermoelectric devices so that the difference between lower and upper operating temperatures could be divided in half, each thermoelectric heat pump then operating through a reduced temperature difference. An analysis of such a system showed that the benefits normally associated with thermoelectric staging cannot be realized in this manner. Two additional temperature differences are imposed to allow for normal heat transfer between the hot end of the low stage and the intermediate sink water, and between the sink water and the cold end of the high stage. Within the limits of reasonable thermoelectric material performance parameters, the additional temperature differences required result in power requirements approximately 25% larger for the staged system than for either of the systems shown in Figs. 4 and 5.

Interest in comparison of performance was consequently limited to the two systems described, one incorporating a thermoelectric water chiller with conventional air cooling coils, the other utilizing a conventional water-to-water heat exchanger with thermoelectric air coolers.

System Analysis. The bulk volume and power requirements of the two thermoelectric systems considered are a function of intermediate sink water temperature. A minimum volume requirement occurs at a particular sink water temperature, different for each system, and at these temperatures a particular power is required for the design load. A lower power requirement may exist at another sink water temperature, but at the expense of increased system volume. In optimizing system design, relative merits of volume and power must then be considered.

Analysis of the two systems on the basis of maximum capacity design and maximum efficiency (i.e., maximum coefficient of performance) design resulted in the type of information shown in Figs. 6 and 7 for the system utilizing the thermoelectric water chiller. Figs. 6 and 7 show heat pumping capacity per unt of system volume and system power per unit of heat pumping capacity. Similar information was developed for the system using thermoelectric air coolers. In the figures shown, the percentages indicated refer to a specified percent of maximum capacity design.

Results for the maximum thermoelectric heat pumping capacity design were obtained by defining the heat pumping capacity of a single pair of thermoelectric elements as

$$q = IST_c - \frac{I^2R}{2} - K\,\Delta t \tag{1}$$

where

q = heat absorbed at the cold junction
I = current
S = Seebeck coefficient for the pair of elements $|S_1| + |S_2|$
T_c = cold-junction temperature
R = electrical resistance per pair of elements
K = thermal conductance per pair of elements
Δt = junction temperature difference

By differentiating equation 1 with respect to current and setting the result equal to zero, a current for maximum capacity is defined as

$$I_{\max\, q} = \frac{ST_c}{R} \tag{2}$$

For selected values of junction Δt, cold-junction temperatures were assumed and calculations were made to determine current for maximum capacity and the resulting capacity. Power required per pair of elements was evaluated as

$$p = I^2R + IS\,\Delta t \tag{3}$$

and the coefficient of performance as q/p at maximum capacity. The heat rejection per element pair from the hot end was expressed in terms of a heat rejection ratio r_h, as

$$q_{rej} = q(r_h) \tag{4}$$

where

$$r_h = 1 + \frac{1}{\text{COP}} \tag{5}$$

Coefficients for either air-side or water-side heat transfer were then calculated and used to determine either cold-junction or hot-junction temperatures, depending on whether calculations were based on the thermoelectric air cooler or water chiller. For the thermoelectric water chiller, the hot-junction temperature can be written in terms of the heat rejected per unit of thermoelectric panel area, $q_{p(\text{rej})}$, as

$$t_h = t_{swm} + \frac{q_{p(\text{rej})}}{(UA)_h} \tag{6}$$

where

t_h = hot-junction temperature
t_{swm} = mean sea-water temperature
$(UA)_h$ = effective heat-transfer coefficient between hot junction and sea water for unit panel area

The cold-junction temperature is then

$$t_c = t_h - \Delta t \tag{7}$$

which must correspond with the value of t_c assumed for equation 2, a process of iteration being required to obtain a final solution.

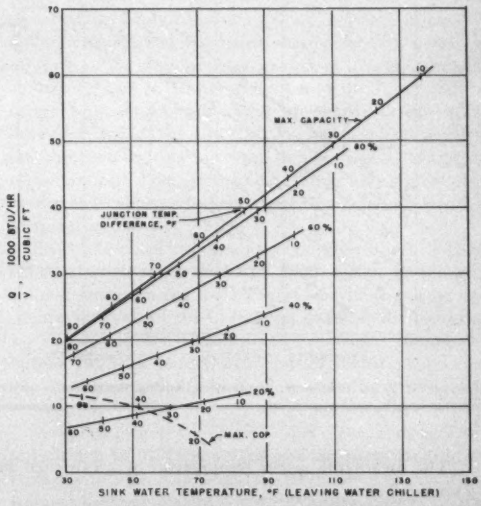


Fig. 6. Q/V vs. sink water temperature leaving thermoelectric water chiller; maximum capacity and maximum COP.

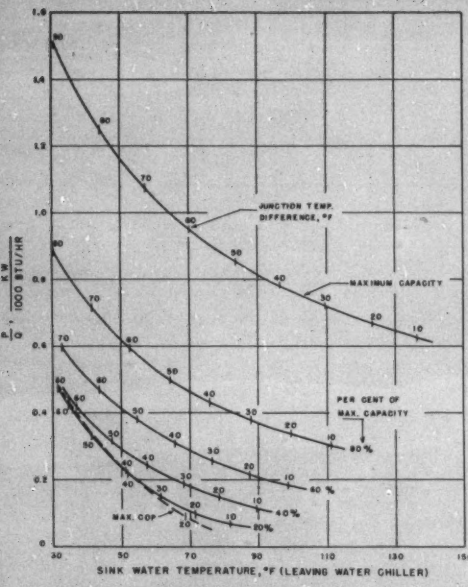


Fig. 7. P/Q vs. sink water temperature leaving thermoelectric water chiller; maximum capacity and maximum COP.

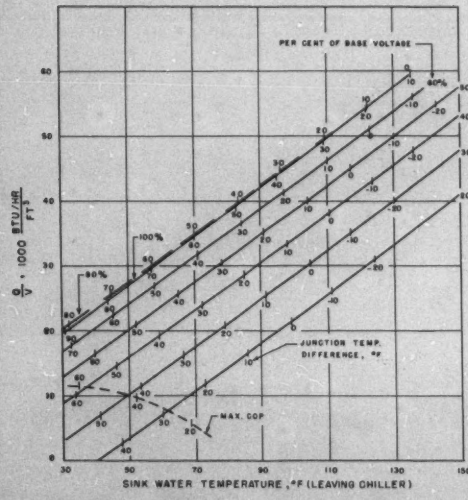


Fig. 8. Q/V vs. sink water temperature leaving thermoelectric water chiller; constant-voltage design.

The mean sink water temperature t_{skm} can then be expressed as

$$t_{skm} = t_c + \frac{q_p}{(UA)_e} \tag{8}$$

where

q_p = heat pumped per unit panel area

$(UA)_e$ = the unit effective heat-transfer coefficient between sink water and cold junction

From the expressions shown, capacity and power were related to sink water temperatures as indicated in Figs. 6 and 7. Results were related to system volume by determining the thermoelectric element size and packing density, as well as the sizes of conventional heat-exchange equipment. A figure of merit Z equal to 2.5×10^{-3} per degree C has been assumed for the analysis presented herein.

The maximum efficiency curves shown in Figs. 6 and 7 were obtained by expressing the coefficient of performance as

$$\text{COP} = \frac{q}{p} = \frac{ST_c - \frac{IR}{2} - \frac{KR(T_h - T_c)}{IR}}{IR + S(T_h - T_c)} \tag{9}$$

The potential difference IR across a pair of thermoelements was then selected to yield a maximum COP by equating $\partial(\text{COP})/\partial(IR) = 0$, resulting in

$$(IR)_{\text{opt}} = \frac{S(T_h - T_c)}{M - 1} \tag{10}$$

$$M = \sqrt{1 + \frac{Z(T_h + T_c)}{2}} \tag{11}$$

$$Z = \frac{S^2}{KR}$$

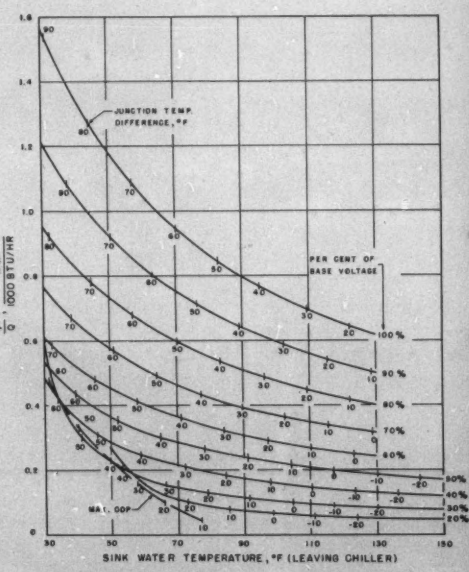


Fig. 9. P/Q vs. sink water temperature leaving thermoelectric water chiller; constant-voltage design.

Equation 10 was then substituted into equation 1 to yield an equation defining capacity at maximum efficiency as

$$q_{max\ COP} = \frac{(K\ \Delta t)\ M}{(M-1)^2\ (2 + Z\ T_c - 2M)} \qquad (12)$$

The curves of maximum efficiency shown in Figs. 6 and 7 were obtained by solving equation 12 for specified values of junction Δt.

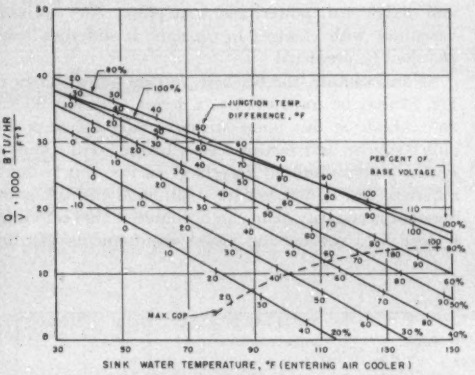

Q/V, 1000 BTU/HR FT³
JUNCTION TEMP. DIFFERENCE, °F
PER CENT OF BASE VOLTAGE
MAX. COP
SINK WATER TEMPERATURE, °F (ENTERING AIR COOLER)

Fig. 10. Q/V vs. sink water temperature entering thermoelectric air cooler no. 1; constant-voltage design.

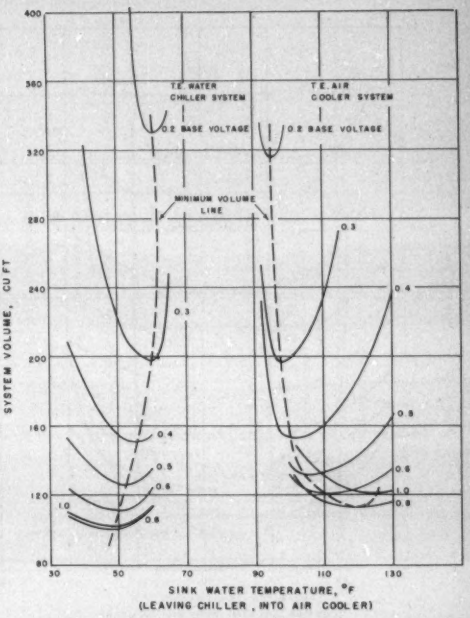


Fig. 12. System volume vs. sink water temperature based on various constant-voltage designs.

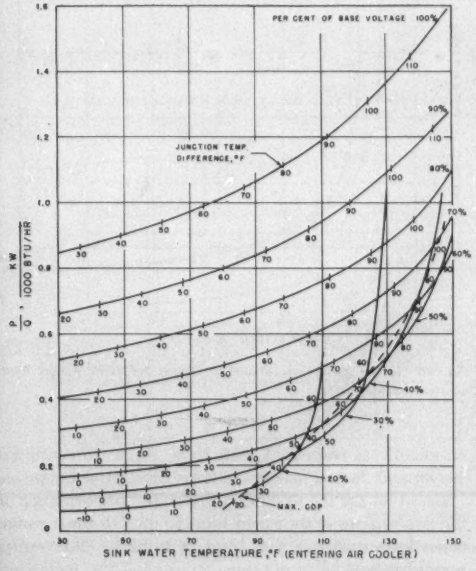

P/Q, KW/1000 BTU/HR
PER CENT OF BASE VOLTAGE
JUNCTION TEMP. DIFFERENCE, °F
MAX. COP
SINK WATER TEMPERATURE, °F (ENTERING AIR COOLER)

Fig. 11. P/Q vs. sink water temperature entering thermoelectric air cooler no. 1; constant-voltage design.

Although reference has been made earlier to the importance of off-design performance studies, it should be observed that the information presented in Figs. 6 and 7 refers to design conditions only. The various curves identified as 0.8 maximum capacity, 0.6 etc., represent different *design* criteria rather than different operating conditions. For any specified load, a particular percentage-capacity curve defines a thermoelectric water chiller or air cooler which will handle the entire design load, but which will be of different physical size and require different power input at a selected sink-water temperature than a unit designed to operate at some other percentage of capacity for the same load and sink-water temperature.

The families of curves shown in Figs. 6 and 7 thus define a broad range of design possibilities. Power and volume requirements for a complete system can be described in terms of the individual components comprising the system. The significance of increased volume requirements with reduction in power requirements can also be shown and can be used for system optimization studies.

Another approach to the establishment of design criteria which lends itself well to analog computer studies is shown in Figs. 8 through 11. Here, an arbitrary base voltage has been assumed, corresponding closely to the average voltage defined by the maximum-capacity curves of the previous figures. The various curves shown as

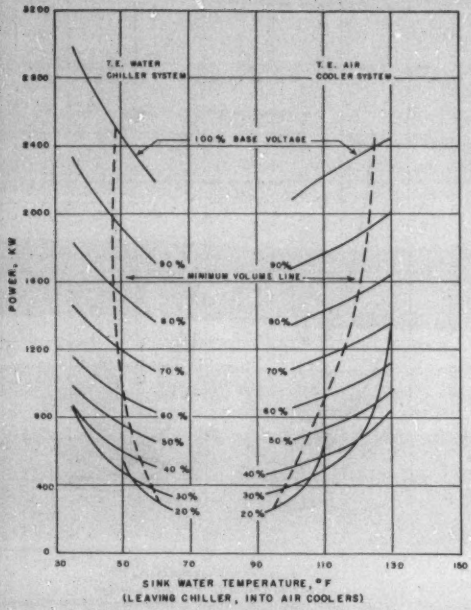


Fig. 13. System power vs. sink water temperature based on various constant-voltage designs.

percentages of base or maximum voltage are thus similar to the percentage of maximum-capacity data shown previously. By using a constant base voltage and percentages thereof, the series of equations shown earlier relating heat transfer performance and the thermoelectric capacity, power, and current were solved simultaneously by means of an analog computer to define capacity and power at different design points for both the thermoelectric water chiller (Figs. 8 and 9) and the thermoelectric air cooler (Figs. 10 and 11).

Since capacity modulation may be achieved by voltage regulation, the design data based on constant voltage are of interest both for system design and for studying performance at off-design conditions.

Off-Design Performance Studies. In order that system performance over a range of sea-water temperatures and loads may be predicted, a complete set of curves similar to Figs. 8 through 11 (which refer only to specific components) was made for all of the components of the system under consideration. For this study, design based on constant voltage was used in preference to the maximum-capacity data in order to utilize the analog computer most effectively.

The over-all system volume and power requirements at 85 F sea-water temperature for various design points and at different percentages of the nominal base voltage are shown in Figs. 12 and 13 for both systems under consideration. A comparison of the two systems based on the minimum system volume lines shown in these two figures is indicated by Fig. 14.

Using these three figures, which (as noted previously) represent different design points for defining total system capacity and power sufficient to provide the entire submarine cooling requirement at maximum load conditions, i.e., 85 F sea water, a particular design point may be selected to study off-design performance. Note that selection of a design point specifies the system size and design load power, and that power and efficiency variations with changes in capacity at different loads can then be predicted.

As an example, the 0.4 base voltage point shown in Fig. 14 may be considered as a design selection. Power and volume at this point are essentially the same for either system, and in this region further reductions in system power result in very large increases in volume requirements, and conversely. Although the 0.4 point does not necessarily define an optimum design selection, it does yield volume and power requirements that are

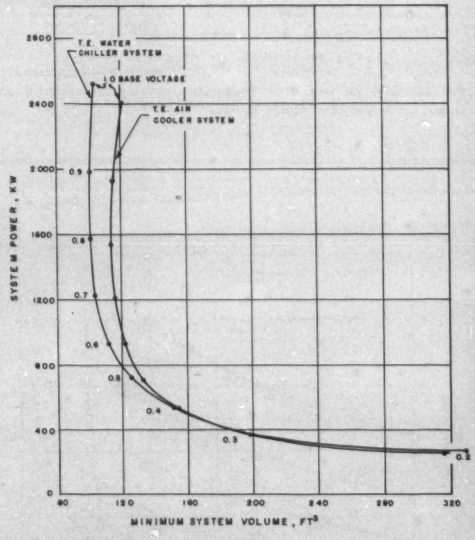


Fig. 14. System power vs. minimum volume for total design load; constant-voltage design.

reasonable as compared with those for a conventional system and, hence, may be used for illustrative purposes.

Based on the 0.4 design selection, the performance of the two systems is shown in Figs. 15 and 16 for a range of sea-water temperatures from 28 to 85 F. The results presented here were obtained by solving the following equations simultaneously using an analog computer. Compartment cooling loads were expressed in terms of sea-water temperature as

$$Q = Q_i + (UA)_0 (t_{sw} - t_a) \tag{13}$$

where

Q = net cooling load
Q_i = internal heat gain
$(UA)_0$ = effective heat transmission coefficient between compartment and sea water
t_{sw} = design sea-water temperature
t_a = compartment air temperature

For convenience, equation 13 was expressed in terms of unit thermoelectric panel area as

$$q_p = \frac{Q}{A_p} = q_i + \frac{(UA)_0 (t_{sw} - t_a)}{A_p} \tag{14}$$

where

A_p = total thermoelectric panel area

For the system utilizing thermoelectric air coolers, the heat transfer to the sea water in the conventional heat exchanger can be written

$$(Q+P) = (q+p)_p A_p = (UA)_{cx}(t_{skm} - t_{swm}) = (wc_p)_{sw}(t_{swo} - t_{sw}) \tag{15}$$

where

Q and P = total rejected heat and power
$(UA)_{cx}$ = effective heat transfer coefficient for conventional exchanger
w_{sw} = weight flow rate of sea water through conventional exchanger
c_{psw} = specific heat of sea water
$(t_{swo} - t_{sw})$ = temperature rise of sea water in passing through exchanger

Since $t_{swm} = (t_{sw} + t_{swo})/2$, equation 15 may be rearranged to express the mean sink-water temperature as

$$t_{skm} = t_{sw} + (q+p)\left[\frac{A_p}{2wc_p} + \frac{A_p}{(UA)_{cx}}\right] \tag{16}$$

The hot-junction temperature may be written as

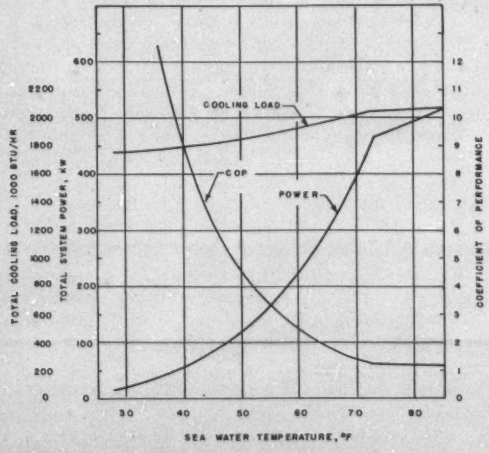


Fig. 15. Off-design performance, complete system, thermoelectric air coolers; 0.4 base-voltage design.

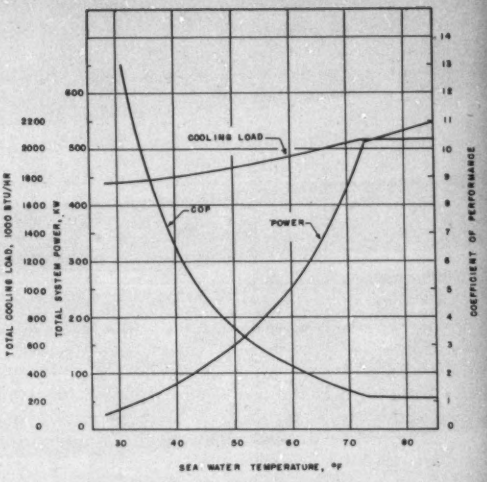


Fig. 16. Off-design performance, complete system, thermoelectric water chiller; 0.4 base-voltage design.

$$t_h = t_{skm} + \frac{(q+p)_p}{(UA)_h} \tag{17}$$

Here $(UA)_h$ is the unit effective heat transfer coefficient between hot-junction and intermediate sink water.

The sensible heat transfer from compartment air to the cold side of the thermoelectric air cooler for unit area is

$$q_s = (UA)_c (t_{am} - t_c) = \frac{(wc_p)_a (t_a - t_{ao})}{A_p} \tag{18}$$

where

$(UA)_c$ = unit effective sensible heat transfer coefficient between compartment air and cold side of thermoelectric air cooler
t_{am} = mean temperature of air passing through cooler
w_a = weight flow rate of air through cooler
c_{pa} = specific heat of air
t_{ao} = air temperature leaving cooler

Since $t_{am} = (t_a + t_{ao})/2$, equation 18 may be rearranged to yield

$$t_c = t_a - q_s\left[\frac{A_p}{2(wc_p)_a} + \frac{1}{(UA)_c}\right] \tag{19}$$

The foregoing equations were combined with the basic thermoelectric equations shown previously as equations 1, 2, and 3, and solved simultaneously on the analog computer by generating the sea-water temperature, feeding it into equations 14 and 16 and plotting it concurrently as the abscissa of the performance curves.

An assumption made in the analysis which is reflected in the results shown in Figs. 15 and 16 is that a selected maximum compartment-air temperature exists at design load, the magnitude depending on the compart-

ment. With decreases in load, this temperature is allowed to reduce until a lower limit is reached, then is held constant by reducing system capacity with further load reduction. System power is limited to that required to maintain the specified maximum compartment temperature at design load. In areas of high latent load, power requirements differ somewhat from those in other areas, contributing to the change in slope of the power curves at about 73 F sea water.

CONCLUSION

FIGS. 15 AND 16 indicate that significant improvement in thermoelectric system performance may be obtained with reduction in load, thus emphasizing the importance of a realistic evaluation of the load. For example, the volume of the conventional system used for comparison in this analysis was approximately 460 cubic feet with a power requirement of approximately 160 kw. On the basis of design load, the thermoelectric system of Fig. 15 has a power requirement of 520 kw, with a volume of about 155 cubic feet. However, at 63 F sea-water temperature, with a reduction in load of only 5%, the power required is reduced 48% and the efficiency is increased 71%.

It is evident from this study that for a comparison of system performance to be meaningful, the conditions of operation must be investigated and the significance of average as well as design load must be considered. The design of a thermoelectric system will be affected both by maximum capacity and maximum efficiency considerations. Proper balance may be achieved by obtaining maximum efficiency at loads representing normal operation with sufficient capacity available to provide for maximum load demands at reduced efficiency.

REFERENCES

1. Thermoelectric Air Conditioning Systems For Submarines. Progress Reports to Bureau of Ships from Research and Development Division, Carrier Corporation, Syracuse, N. Y.

2. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. F. Ioffe, Infosearch, Ltd., London, England, 1957.

3. Introduction To Heat Transfer, (book), A. I. Brown, S. M. Marco, McGraw-Hill Book Company, Inc., New York, N. Y., 3rd ed. 1958.

Improved Surveillance Drone Flight Tested

An improved version of the Aerojet General SD-2 Surveillance Drone was successfully flown April 19, at the United States Army Test Station near Yuma, Ariz. The SD-2 is a development of the Aerojet-General Corporation, Downey, Calif., a subsidiary of the General Tire and Rubber Company, Akron, Ohio. It was the first launching of this drone configuration and it follows year-long successful flight testing of the original SD-2 version on both day and night missions.

Improvements in performance and mission capability are the primary differences between the drone and its predecessor. The external configuration of the drone is basically the same, but redesign has improved the aerodynamics of the craft. A longer fuselage makes it possible for the improved SD-2 to carry radar, infrared, high-speed photographic cameras, as well as combinations of these equipments, and other of the Army's most recently developed sensory devices.

Designed especially for modern Army battlefield surveillance needs, the SD-2 was originally selected for continued development and testing after competitive flight tests with another drone, which were conducted by the Army last year.

Remote control of the drone by radio command is supplemented by a programmer, located on board. Zero-length launched from a modified Army trailer, the drone is assisted by two rocket motors which eject automatically following burnout. Drone recovery is accomplished by means of a parachute which deploys upon radio command.

Developed for the U. S. Army, the SD-2 program is under the cognizance of the U. S. Army Signal Corps, Electronic Proving Ground, Fort Huachuca, Ariz.

Reliability Analysis for Aircraft Generators

J. T. DUANE
ASSOCIATE MEMBER AIEE

L. J. YEAGER
ASSOCIATE MEMBER AIEE

MUCH HAS BEEN WRITTEN on the subject of reliability, but there still exists a need for industry-wide agreement on a precise definition of the meaning of the numerical value of reliability associated with specific pieces of equipment.

Before proceeding with a mathematical definition, it should be recognized that there are two types of reliability: (1) operational reliability and (2) simulated-service reliability. The first is the actual reliability of the equipment in service and represents the single-end result of any worthwhile reliability program. However, a measurement of this reliability cannot be obtained until the equipment has been in service a long period of time. There is need for some index of reliability which can be determined prior to operational use. Such an index might be referred to as simulated-service reliability. When properly measured, it will provide an estimate of operational reliability if the specifications defining the tests accurately portray the actual application conditions.

For aircraft motors or generators it seems logical to define reliability as the probability that the equipment will successfully complete a single mission. It is also logical to conclude that this probability will vary with time, being higher at the start of the design life than near the end. Thus, any mathematical definition must allow for both time and mission length. With the aid of mathematical statistics it can be shown that the expected value of instantaneous component reliability is

$$R = \frac{\int_0^{T_r} G(t+h)\,dt}{\int_0^{T_r} G(t)\,dt} \qquad (1)$$

where

h = mission length
t = time
T_r = replacement time for component
$G(t+h)$ = probability of being alive at end of mission
$G(t)$ = probability of being alive at start of mission

Equation 1 states that the reliability is the mean value observed in service or on test of successfully completing a single mission. The authors feel that this definition is the most realistic for the specification of component reliability. Operational reliability can easily be measured if defined by equation 1, for then it is simply the ratio of successful missions to total missions when observed over a long period of time.

Evaluation of equation 1 is possible, provided that the failure rate of the component is known. Failure rate is usually expressed as the conditional probability density of failures which is the probability density of failure at time t, given the condition that the item is alive at t. From the analysis of field data, the failure rate of aircraft generators and motors shows a wear-out phenomena and also a random failure rate which can be represented by the following function:[1]

$$z(t) = \frac{1}{\theta_r} + \frac{m}{\theta_t^m} t^{m-1} \qquad m \geq 1 \qquad (2)$$

where

θ_r = random failure parameter
θ_t = wear-out parameter
t = time

With the use of mathematical statistics it is possible to go from $z(t)$ to the function $G(t+h)$ or $G(t)$. Thus the R_e reliability is completely specified once the $z(t)$ function is known.

Simulated-service reliability can be measured most economically and efficiently by the use of sequential analysis techniques. Unfortunately, the mathematics involved in establishing test criteria for two parameters is very complicated. One solution is to determine the parameter θ_t from component data and then set up a conventional sequential analysis test to determine θ_r. Test limits on θ_r are established with the aid of equation 1.

Several conclusions may be drawn from the discussion:

1. Operational reliability and simulated-service reliability are two different things and should be clearly recognized as such.
2. Reliability for an item which must operate for several missions should be defined as the expected value of the probability that it will successfully complete a randomly selected mission (R_e).
3. Aircraft generators exhibit a conditional probability density of failure that increases with time and is non-zero at $t = 0$ (see equation 2).
4. Simulated-service reliability for aircraft generators can be measured by determining a value for the parameter θ_t from previous component tests and then employing conventional sequential analysis techniques to measure θ_r.

REFERENCE

1. Two-Parameter Lifetime Distributions for Reliability Studies of Renewal Processes, G. J. Flehinger, P. A. Lewis. *Journal of Research and Development*, International Business Machines Corporation, New York, N.Y., vol. 3, no. 1, Jan. 1959, pp. 58-73.

Digest of paper 59-888, recommended by the AIEE Air Transportation Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Summer and Pacific General Meeting and Air Transportation Conference, Seattle, Wash., June 21-26, 1959. Published in AIEE *Applications and Industry*, Jan. 1960, pp. 426-34.

J. T. Duane and L. J. Yeager are with the General Electric Company, Erie, Pa.

THERMOELECTRICITY

Operating Properties of Thermoelectric Generator Materials

M. G. RYAN

N. J. STEVENS

A brief exposition of the thermodynamics of thermoelectricity and a discussion of the measurement techniques developed to provide quality control data for the selection of thermoelectric material.

THE MEASUREMENT of the properties of thermoelectric materials in general presents many problems. This is particularly true of those materials intended for use in power generation since those transport properties of interest must be found either isothermally over a large temperature range or preferably as averages in the temperature gradient.

The measurement techniques described in this article were developed primarily to provide quality control data for the selection of thermoelectric material in fulfillment of a contract with the Bureau of Ships, Department of the Navy. This contract requires meeting a guaranteed minimum performance for a thermoelectric generator but specifically does not cover any thermoelectric material research. Accordingly, the approach was to obtain the best material available commercially and measure the actual properties under operating conditions. Material specifications were then set to give the required performance.

All thermoelectric material for this contract was supplied by Minnesota Mining and Manufacturing Company. Both p- and n-type elements are compressed and sintered lead telluride powders, suitably doped, and both types are segmented so as to maintain a high figure of merit throughout the operating temperature range.

BACKGROUND THEORY

THE ARGUMENTS presented in the remainder of the article require for understanding a brief exposition of the thermodynamics of thermoelectricity. The work presented here is treated more thoroughly by Ioffe[1] but with a slightly different viewpoint.

Consider the element of Fig. 1, heated to temperature T_1 at one end and rejecting heat at temperature T_0 at the other. Both ends of the element are assumed to be in contact with a conducting metal with zero absolute thermoelectric power. It is further assumed that the system is in equilibrium, with no variables changing with time, and that heat flow is one dimensional.

A special article recommended for publication by the AIEE Solid State Devices Committee.

M. G. Ryan and N. J. Stevens are with the Carrier Corporation, Syracuse, N. Y.

The Peltier heat absorbed at the hot end is

$$Q_{p1} = \alpha_1 T_1 I$$

where

α_1 = the local Seebeck coefficient.

The heat rejected at the cold end due to the Peltier effect is

$$Q_{p0} = -\alpha_0 T_0 I$$

The Thomson heat generated as current flows along the element is

$$Q_T = -\int_{T_0}^{T_1} T(d\alpha/dT)\, I\, dT$$

In the special case when α = constant, analysis is made simple because $Q_T = 0$ and $\alpha_1 = \alpha_0 = \alpha$. The same simplification can be achieved by defining an average Seebeck coefficient.

$$\alpha = \frac{\alpha_1 T_1 - \alpha_0 T_0 - \int_{T_0}^{T_1} T(d\alpha/dT)\, dT}{T_1 - T_0} \quad (1)$$

The useful heat absorbed by the element is now

$$Q_p = \alpha\, T_1 I \quad (2)$$

The heat flux through the element due to heat conduction is

$$Q_c = K\, \Delta\, T \quad (3)$$

where

K = the thermal conductance of the element.

The total Joule heat generated is I^2R, of which 1/2

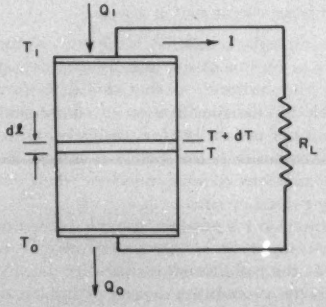


Fig. 1. Thermoelectric element.

returns to the hot junction. This statement is not strictly true, however, since if the product RK varies with temperature, some fraction of the Joule heat slightly different from 1/2 returns to the hot junction. A further assumption is made, therefore, that RK is approximately independent of temperature.

The total heat flow into the element is then

$$Q = Q_p + Q_e - \tfrac{1}{2} I^2R = \alpha T_1 I + K \Delta T - \tfrac{1}{2} I^2R \tag{4}$$

The Seebeck emf is

$$E = \alpha \Delta T \tag{5}$$

The terminal voltage is then

$$V = E - IR = \alpha \Delta T - IR \tag{6}$$

Power output W is given by

$$W = VI = \alpha \Delta T I - I^2R \tag{7}$$

The power can also be written in terms of the load resistance R_L as

$$W = V^2/R_L = (\alpha \Delta T - IR)^2/R_L \tag{7a}$$

Element efficiency is then

$$\eta = (\alpha \Delta T I - I^2R)/(\alpha T_1 I + K \Delta T - \tfrac{1}{2} I^2R) \tag{8}$$

which reduces to

$$\eta = \frac{\Delta T}{T_1} \frac{\dfrac{1}{1 + R/R_L}}{1 + \dfrac{1}{Z} \dfrac{(R_L/R + 1)}{T_1} - \dfrac{1}{2} \dfrac{\Delta T}{T_1} \dfrac{1}{R_L/R + 1}} \tag{9}$$

where α^2/KR has been replaced with Z.

Differentiating equation 9 with respect to R_L/R and equating to zero yields an optimum value of R_L/R.

$$R_L/R = \sqrt{1 + \tfrac{1}{2} Z (T_1 + T_0)} = M \tag{10}$$

and

$$\eta_{opt} = \frac{\Delta T}{T_1} \frac{M - 1}{M + \dfrac{T_0}{T_1}} \tag{11}$$

Similarly, from equation 7a, it can be determined that for maximum power

$$R_L/R = 1 \tag{12}$$

The efficiency at maximum power is, from equations 12 and 9

$$\eta = \frac{1}{2} \frac{\Delta T}{T_1 + \dfrac{2}{Z} - \dfrac{1}{4} \Delta T} \tag{13}$$

The maximum power output, moreover, is from equation 7a:

$$W = E^2/R - 2EI + I^2R$$

But

$$I = E/(R + R_L) = E/2R$$

Combining

$$W_{max} = E^2/4R \tag{14}$$

For lead telluride a typical mean value of Z is about 1.25×10^{-3} per degree C. Using this value, and $T_1 = 550$ C, $T_2 = 50$ C, we obtain

$$M = 1.31$$

At maximum efficiency

$$I = \alpha \Delta T/(R_L + R) = E/(R_L + R)$$

From equation 7

$$W = 0.245\ E^2/R$$

From equation 14

$$W_{max} = 0.250\ E^2/R$$

Therefore, the drop in power between maximum power and maximum efficiency points is very small.

MATERIAL SPECIFICATIONS

THE ORIGINAL GENERATOR thermoelectric design was done by the method described by Talaat.[2] Samples were obtained to this design and were tested. The test results were then used to fix final specifications.

It should be emphasized that the properties of lead telluride and, in fact, of any of the thermoelectric semiconductors are not precisely controllable as yet. Furthermore, if any of the simplifying assumptions made in the previous section are not made, the design problem becomes very complex. As a consequence, it could not be expected that the initial design would be anything more than a first approximation. It was for this reason that the experimental program, between the original design and the setting of the specifications, was undertaken.

In setting the specifications, four general considerations had to be covered:

1. The physical size of the elements had to be controlled to ensure a good fit in the thermoelectric panel.
2. The minimum power output had to be specified in some way to ensure that the final generator met the product specifications.
3. The element efficiency should be controlled.
4. The element open-circuit voltage should be controlled.

The first of these, the physical size, was specified by means of a conventional sketch. Tolerances were, in general, held fairly closely. It was found, however, that the position of the segmentation plane of the elements could vary considerably with little or no effect on performance. The tolerance on segmentation plane position was, therefore, loosened considerably from its original value.

Minimum power output per element was specified by stipulating a minimum value of E^2/R at design ΔT. Reference to equation 14 will show that this is just four times the maximum power output of the element. Strictly speaking, it would have been better to specify power output at maximum efficiency. As is pointed out later, however, this would have led to a very large increase in test effort. Also, the typical data given at the

end of the last section indicate that there is little difference between maximum power and power at maximum efficiency for lead telluride.

In order to control element efficiency or power at maximum efficiency, a measurement of thermal conductivity, either directly or indirectly, would have been necessary. It is known, however, that with a given doping, the thermal conductivity of lead telluride is not strongly affected by trace impurities, and furthermore, small changes in doping do not have an appreciable effect on thermal conductivity. It is, therefore, reasonable to assume that thermal conductivity is constant. With this knowledge and knowing as well the difficulties inherent in any method of measuring thermal conductivity, it was decided that no conductivity specification would be made. In lieu of this specification nominal doping concentrations were specified. In combination with the E^2/R specification, this controls both the element efficiency and (approximately) the power output at maximum efficiency.

The fourth quality control requirement, that of specifying open-circuit emf, was met by specifying a mean value of E, with a tolerance band of about $\pm 8\%$ about the mean permitted. In setting the specification, it was assumed that the distribution of E would be gaussian.

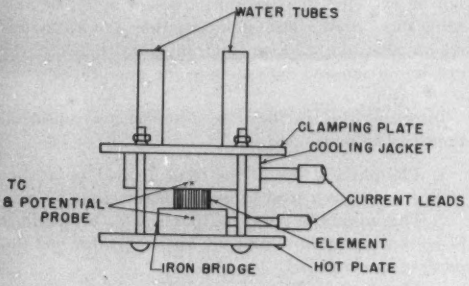


Fig. 2. Element test module.

The philosophy used in the test work was directed toward duplicating within reason the final generator configuration. Consequently, the element internal resistance was understood to include bond resistances at both ends. It is evident that small differences in position of the voltage probes may make significant differences in resistance measurements. To avoid any discrepancies in test results between work done by Minnesota Mining and Manufacturing Company and by Carrier Corporation, identical test fixtures were made for use in quality control tests at each location.

EXPERIMENTAL WORK

To SIMULATE the actual operational conditions of the generator, a test module (Fig. 2) was built. The element to be tested was soldered to the cooling jacket using

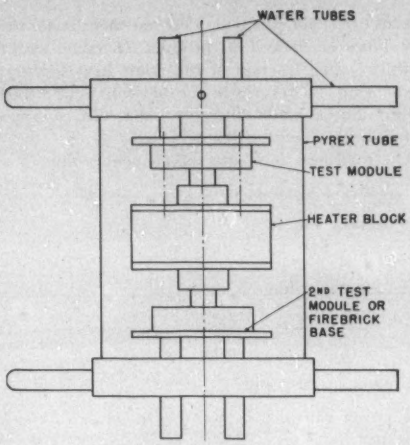


Fig. 3. Test oven.

bismuth-tin solder. The pressure joint on the hot side was maintained during heating with Belleville washers under the nuts. Between the hot plate and the iron blocks, mica was used as the electrical insulation; between the cooling jacket and clamping plate, silicon rubber was used. The space around the element between the iron block and the cooling jacket was loosely packed with cerofelt to prevent direct heating of the cooling jacket. The temperatures were measured with 36-gauge chromel-alumel thermocouples; 30-gauge copper wire was used as potential leads. The current leads were no. 6 welding cable with the rubber insulation replaced with Fiberglas tape on the hot side. This module could be used to test single elements as shown in Fig. 1 or with a few adjustments to test couples.

Basically, the oven in which these modules were tested consisted of a water-cooled top and bottom plate separated by a 100-mm diameter pyrex tube. During tests the module rested on a steel block in which were embedded electric cartridge heaters of at least 400 watts capacity. Depending on the method of data taking, tests were run on a single module or two modules at a time by sandwiching the heater block between them. Since no attempt was made to seal the oven, the forming atmosphere required by the elements was maintained by a constant flow of gas. The oven with test modules is shown in Fig. 3.

In this main series of tests, the quantities of interest were the open-circuit voltage and the internal resistance. Knowing the open-circuit voltage E, the closed-circuit voltage V, and the current I, all at the same temperature difference, the internal resistance R can be calculated as

$$R = [(E-V)/I]_{\Delta T}$$

With the potential probes located as shown in Fig. 2,

the internal resistance includes the contact resistance. Using the element resistance supplied by the manufacturer, the contact resistance can then be determined. No provisions were made to measure the thermal conductivity nor the efficiency with this apparatus.

The test procedure was to purge the atmosphere of the oven for 10 minutes, turn on the water, and then heat up the iron block to 700 C or slightly higher for about 15 minutes to seat the element properly on the iron block. When the testing program was initiated, data were taken using a Rubicon potentiometer. The system was allowed to come to equilibrium in the closed-circuit state at some temperature above the design operating temperature. The hot temperature, cold temperature, voltage, and current were recorded, the circuit broken, and the system allowed to come to equilibrium again and these data recorded. Then this process was repeated for at least three lower temperatures. Finally, the open- and closed-circuit voltage, current, and calculated resistance were plotted vs. the temperature difference. Although this process is quite long, two modules can be tested simultaneously since both come to equilibrium in the same length of time. One drawback to this method is that it is difficult to maintain a constant cold-junction temperature. Fig. 4 shows a graph of data taken with this method.

Later in the testing program, data were taken with an *X-Y* recorder; voltage leads connected to *X* scale and hot temperature to *Y* scale. This method is still in use.

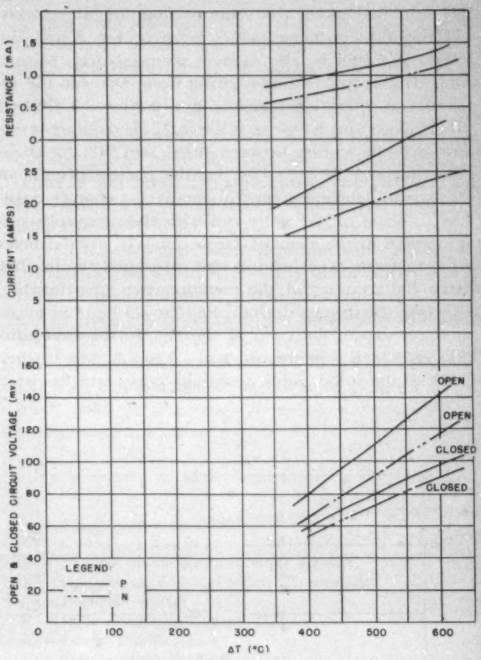


Fig. 5. Element performance from recorder data.

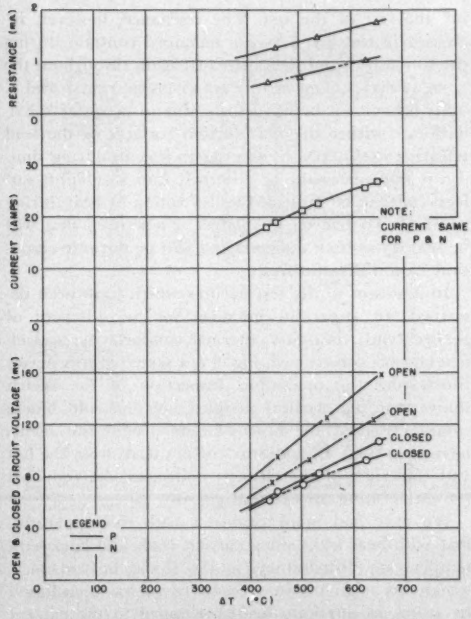


Fig. 4. Element performance from potentiometer data.

As just described, the hot side is taken up to 700 C in closed-circuit state, then the heaters are turned off, and the voltage and temperature are simultaneously recorded as they fall. The cold-junction temperature is maintained at 25 C during the test run. The current is read at certain predetermined temperatures. After the temperature has reached 400 C, the recorder is turned off and the hot temperature brought back to 700 C. The circuit is broken, the heaters are turned off and the recorder is turned back on. The value of the resistance at operating temperature could then be calculated from the recorder graphs. This method is much faster even though one module is tested at a time. Fig. 5 shows a graph of the data obtained with the recorder.

The recorder method is based on the assumption that if the system is initially in equilibrium, then it maintains itself in equilibrium as the temperature falls. A second assumption is that the reheating does not harm the elements. As far as it can be determined from comparison tests run at Carrier and Minnesota Mining and Manufacturing Company on similar elements, these two assumptions are valid. The difficulty in actually determining whether or not a small discrepancy due to methods exists is that no two elements will test exactly the same. Fig. 6 shows the distribution of open-circuit voltages and resistances for a group of elements that were made from the same batch of material the same

day and in exactly the same manner in all respects.

Using the resistance values given in Fig. 6 and the values supplied by the element manufacturer, Minnesota Mining and Manufacturing Company, for the resistance at operating temperatures [p-type = 0.870 mΩ (milliohms) and n-type = 0.528 mΩ], the contact resistance is found to vary between 40.5% and 54% for the n elements, and 20% to 44% for the p elements. In an attempt to determine experimentally the contact resistance, a series of tests were run with thermocouple-voltage probes in the element. Unfortunately, discrepancies arose between experimental and calculated results that make the accuracy of the measurements questionable. However, these tests do indicate that of the total measured resistance, the ratio of the hot- to the cold-junction resistance is of the order of 1.5 to 1.0. As a further check of the solder joint, resistivity measurements were

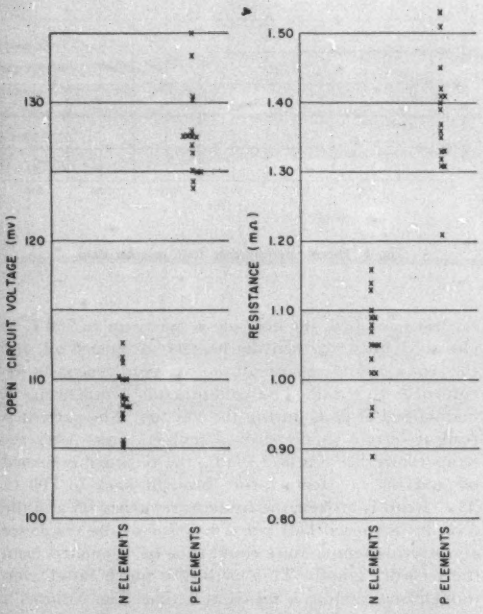


Fig. 6. Distribution of open-circuit voltage and resistance.

made before and after soldering the element to the water jacket. Comparison of these values showed that the act of soldering did not increase the resistance providing that the joint was well made.

Finally, the effect of long time cycling of a p-n couple was investigated. The test was started and allowed to heat and cool for 7 cycles and then shut down. After 3 days, the test was started again and allowed to cycle continually for the next 3 days. The open-circuit voltage remained constant for the first 7 cycles, decreased over the 3-day shut down, but remained at this lower value

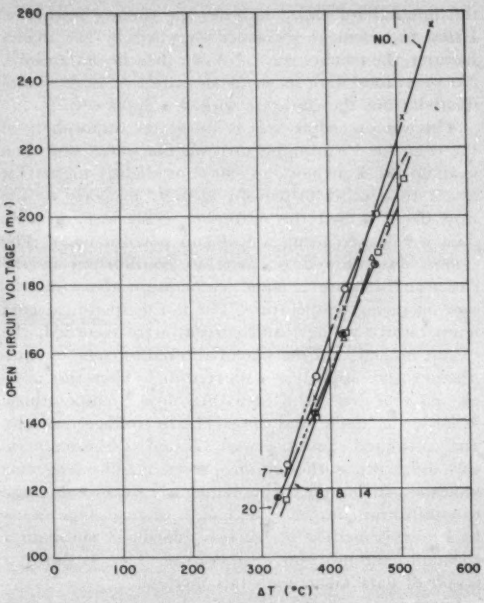


Fig. 7. Life test, cycled on and off; open-circuit voltage. Numbers labelling curves indicate the number of the cycle in which measurements were taken.

for the rest of the test. The resistance, however, increased in the first 7 cycles, remained constant during the shut-down, and then increased again throughout the next 12 cycles. Test results are given in Figs. 7 and 8. This behavior is believed to be due to progressive oxidation of either the hot-junction surfaces or the lead telluride itself. Oxygen was free to leak in during shut-down when it could be adsorbed into insulation surfaces, later to be subjected to desorption by heat during running. To remedy this defect, a new oven that will be sealed has been designed and will be put into operation in the near future.

In addition to the test fixtures which have been described, an apparatus intended for measurement of Seebeck emf, resistance, thermal conductivity, and efficiency was constructed. Fig. 9 is a sketch of this device illustrating the operation. Inspection of the sketch shows that the classical shielded hot and cold blocks commonly used for heat conductivity measurements have been used. In addition, current leads from the hot and cold sides of the element under test are provided for establishing an external circuit.

We have had many problems with this apparatus, first with heat leaks along current leads and later with temperature distributions in the shield heater block, which was originally iron. Some success has been found by using an auxiliary heater strapped to the current lead and by changing the shield material to copper. The

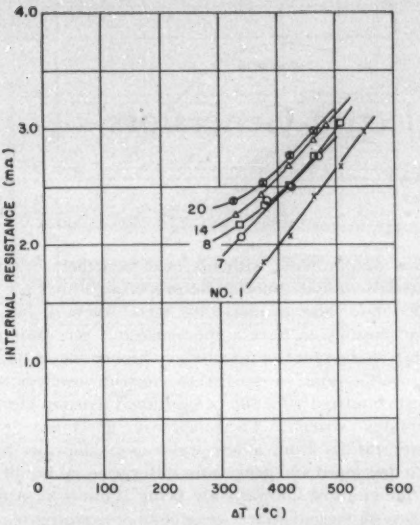


Fig. 8. Life test, cycled on and off; internal resistance. Numbers labelling curves indicate the number of the cycle in which measurements were taken.

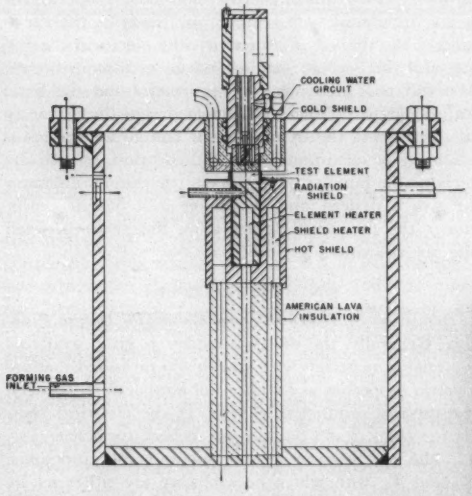


Fig. 9. Test fixture for measurement of element Seebeck coefficient, resistance, and thermal conductivity.

results are not yet satisfactory for publication, but the technique appears promising and we are continuing to work on it. In particular, some measurements of thermal conductivity have been made with estimated error varying from less than 10% at a ΔT of 300 C to about 12% at a ΔT of 600 C. It is believed that further refinements will reduce the error appreciably.

CONCLUSIONS

THERMOELECTRICITY is rapidly approaching the production phase in its development although until recently it has been relegated almost completely to the laboratory. The work described here was done in a laboratory as well but on a large enough scale so as to approach in its dimensions a production operation. If this article has merit, it is surely in its descriptions of how the quality control problems were met.

The test fixtures described are simple and easy to use and yield accurate data when properly used. The problem of measuring "in-gradient" thermal conductivity has been troublesome for us, but some progress is being made, and we take heart in the realization that it is troublesome for others as well.

NOMENCLATURE

E = Open-circuit voltage, volts
I = Current, amperes
K = Thermal conductance, watts per degree C
M = Optimum ratio of load-to-internal resistance
Q = Heat flow, watts
R = Internal resistance, ohms
R_L = Load resistance, ohms
T = Temperature, degrees C
V = Terminal voltage under load, volts
W = Power output, watts
Z = Thermoelectric figure of merit, per degree C
α = Seebeck coefficient, volts per degree C
η = Thermal efficiency

REFERENCES

1. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. I. Ioffe, Infosearch, Ltd., London, England, 1957.

2. Synthesis of Thermoelectric Generators, M. Talaat. *Electrical Engineering*, vol. 79, no. 6, June 1959, pp. 476-81.

Experimental transmitting station buried in a mine shaft in the Mojave Desert enables Space Electronics Corporation, Glendale, Calif., to conduct research into techniques of communication beneath the earth's surface using electromagnetic waves.

Synthesis of Thermoelectric Generators

M. E. TALAAT
MEMBER AIEE

This article presents a guide for the design of any thermoelectric generator to yield a given output for a given heat source and heat sink. The design procedure takes into account the Thomson effect, as well as the variations with temperature of the thermoelectric properties of a set of materials.

THERMOELECTRICITY is an old science dating back to 1822 to 1823 with the discoveries of Seebeck and to 1834 with the discoveries of Peltier, and later in the middle of the 19th Century, with the interpretation of Seebeck and Peltier experimental results and the discovery of the Thomson effect by W. Thomson.

The direct conversion of heat to electricity using thermoelectric principles has, since these discoveries, been a dream of engineers and scientists. However, this dream has been frustrated by the poor thermoelectric properties of the metals and metal alloys tried. Thermoelectric generators built in the early 20th Century, using metallic couples, reached efficiencies of only a fraction of 1% and had an extremely high ratio of weight to power output. Now, with advent of new thermoelectric materials with thermoelectric properties which are far superior to those of metal and metal alloys, it has become possible to have a thermoelectric generator efficiency in the range of 5 to 10% or higher and to have a reasonable ratio of weight to electric power output when compared with the conventional dynamo electric generator systems. Thermoelectric generators with power ratings from a few watts to 5 kilowatts have been developed and generators with ratings of hundreds or thousands of kilowatts are being considered. Applications of thermoelectric generators are coming of age and a new generation of thermoelectric generator designers is needed.

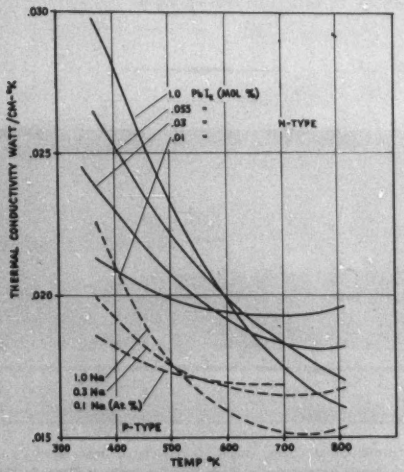


Fig. 1. Thermal conductivity as a function of temperature for p- and n-type PbTe with various percentage dopings.

The purpose of this article is to assist engineers who are called upon to design a thermoelectric generator to yield a given output for a given heat source and heat sink. The synthesis procedure presented takes into account the variation of the thermoelectric properties of a given material with temperature; namely, the variation of the thermal conductivity, the electrical resistivity, and the Seebeck emf coefficient with temperature. We will proceed from these properties and the basic knowledge of thermoelectricity to design the geometry of the arms of the thermoelectric couple for optimum efficiency or maximum power. In addition, we will determine the number of thermoelectric couples necessary to give a desired output voltage and output power under the prescribed temperature difference between the hot and cold junctions.

SYNTHESIS PROCEDURE

Definition of Thermoelectric Generator Design Problem. Generally, the design engineer is given available material or materials with known and measured thermoelectric properties as functions of temperature, namely, the thermal conductivities (Fig. 1), the electrical resistivities (Figs. 2 and 3), and the Seebeck coefficient (Fig. 4). The temperature at the hot and cold junctions, T_h and T_c, with which he can work are either set by the thermoelectric material limitations or they are set by the type of heat source (isotopic, reactor, fossil fuel

Essentially full text of a conference paper presented at the AIEE Winter General Meeting, New York, N. Y., Jan. 31-Feb. 5, 1960. Recommended for publication by the AIEE Solid State Devices Committee.

M. E. Talaat is chief of the Energy Conversion Laboratory, Nuclear Division, The Martin Company, Baltimore, Md.

The author wishes to thank Dr. R. W. Fritts of the Minnesota Mining and Manufacturing Company for permission to use the company's PbTe p- and n-type material data which appear in Figs. 1 through 4, 6, and 7.

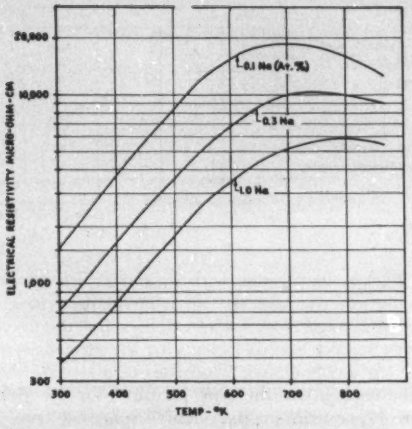


Fig. 2. Electrical resistivity vs. temperature for p-type PbTe.

flame, or hot gas) and by the type, size, and weight limitations of the heat sink. Here we are not concerned about how the temperatures at the hot or cold junctions are to be maintained. This is part of the generator system heat transfer design and is given elsewhere.[1]

Here we are dealing specifically with the problem facing the electrical design engineer who is given an electric power output rating which he is required to meet with a given temperature difference and given thermoelectric materials. He is concerned primarily with the problem of determining the number of and the geometry of the thermoelectric arms, whether segmented or nonsegmented, which would yield the output voltage required and the output power at the highest possible efficiency.

Solution of the Thermoelectric Generator Design Problem. In the case of the nonsegmented thermoelectric arm, the p- or n-type arms of each thermoelectric couple of the generator is composed of one homogeneous material. T_h and T_c are the hot- and cold junction temperatures; L_p and L_n are the lengths of the p- and n-type arm, respectively; κ_p, ρ_p, α_p are the thermal conductivity, electrical resistivity, and Seebeck emf coefficient, respectively, as functions of temperature for the p-type arm; and κ_n, ρ_n and α_n are the corresponding functions of temperature for the n-type arm. (In order to conserve space, throughout this article equations only for the p-type arms or junctions will be given. To obtain "n" values, use the "p" equations, changing all p subscripts given to n, and all n subscripts given to p.) From the properties of the chosen thermoelectric materials for the p- or n-type arm we can calculate the effective average thermal conductivity, effective average electrical resistivity, and the effective average Seebeck coefficient for a nonsegmented p- or n-type arm over the temperature range T_h to T_c. These effective average quantities are given as follows:

$$\bar{\kappa}_p = \frac{\int_{T_c}^{T_h} \kappa_p \, dT}{T_h - T_c} \tag{1}$$

$$\bar{\rho}_p = \frac{\int_{T_c}^{T_h} \kappa_p \rho_p \, dT}{\int_{T}^{T_h} \kappa_p \, dT} \tag{2}$$

$$\bar{\alpha}_p = \frac{\int_{T_c}^{T_h} \alpha_p \, dT}{T_h - T_c} \tag{3}$$

$$\bar{\alpha} = \bar{\alpha}_p + \bar{\alpha}_n \tag{4}$$

Let us introduce an effective Seebeck emf coefficient α_{eph} or α_{enh} at the hot p- or n-type junction, which takes into account the Thomson effect:

$$\alpha_{eph} = \alpha_{ph} - a_{\tau p}(\alpha_{ph} - \bar{\alpha}_p) - a_{\tau p}(\bar{\alpha}_p - \alpha_{pc})\frac{T_c}{T_h} \tag{5}$$

$$\alpha_r = \alpha_{eph} + \alpha_{enh} \tag{6}$$

where $a_{\tau p}$ is the fraction of the Thomson heat which is fed back to the hot junction, and is given as follows:

$$a_{\tau p} = \frac{\int_{T_c}^{T_h} \left(\int_{T_c}^{T} \kappa_p \, dT \right) T \frac{d\alpha_p}{dT} \, dT}{\left(\int_{T_c}^{T_h} \kappa_p \, dT \right) \left(\int_{T_c}^{T_h} T \frac{d\alpha_p}{dT} \, dT \right)} \tag{7}$$

The fraction of the Joule heat which is fed back to the hot junction from the p- or n-type arm is designated by a_{jp} or a_{jn}, respectively.

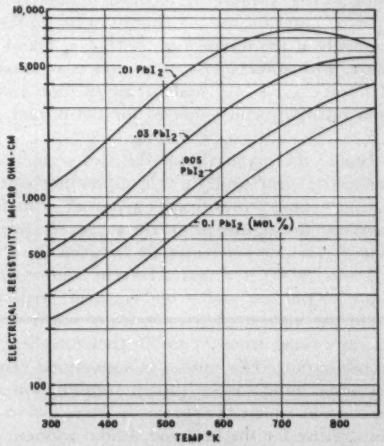


Fig. 3. Electrical resistivity vs. temperature for n-type PbTe.

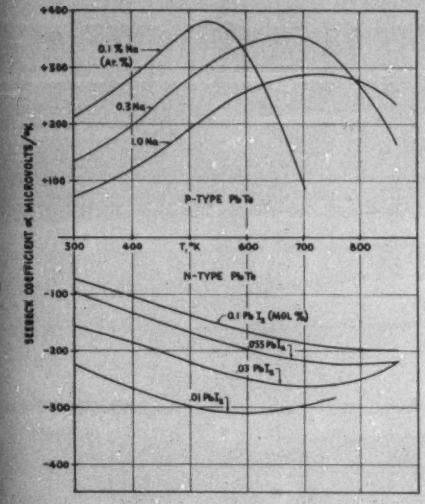


Fig. 4 (*left*). Seebeck emf coefficient vs. temperature for p- and n-type PbTe.

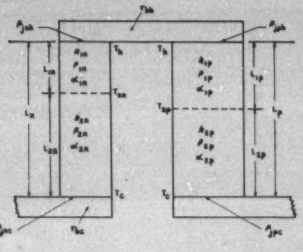


Fig. 5 (*right*). Doubly segmented thermoelectric couple.

$$\alpha_{jp} = \frac{\int_{T_c}^{T} \left(\int_{T_c}^{T} {}_{p}\, dT \right) \kappa_p \rho_p \, dT}{\left(\int_{T_c}^{T_h} \kappa_p \, dT \right) \left(\int_{T_c}^{T_h} \kappa_p \rho_p \, dT \right)} \tag{8}$$

In the case of the doubly segmented thermoelectric arm, the arm of each thermoelectric couple of the generator is composed of two homogeneous materials which are connected together at the segmenting plane. Fig. 4 shows a sketch of a typical doubly segmented thermoelectric couple. T_h and T_c are the hot- and cold-junction temperatures; T_{sp} and T_{sn} are the optimum segmenting temperatures; L_p and L_n are the lengths of the p- and n-type arms; L_{1p} and L_{2p} are the lengths of the first and second segment of the p-type arm corresponding to the optimum segmenting temperature T_{sp}; similarly, L_{1n} and L_{2n} are the lengths of the corresponding segments of the n-type arm for T_{sn}; κ, ρ, and α, are as before, with subscripts 1, 2, p, and n as noted previously; and ρ_{jph}, ρ_{jpc}, ρ_{jnh}, and ρ_{jnc} are the hot- and cold-junction resistivities in ohm-cm² for the p- and n-type arms.

To choose the materials for the two segments of a thermoelectric arm and the corresponding optimum segmenting temperatures from a given set of materials, we examine the figure of merit curves vs. temperature for a given set of materials between T_c and T_h (Figs. 6 and 7). We see that a certain combination of materials for the first and second segment, respectively, will yield the highest effective figure of merit over the temperature range from T_h to T_c; therefore, we choose that combination. The optimum segmenting temperature corresponding to the chosen combination is the temperature at which the curves of the figure of merit vs. temperature for the first and second segment materials intersect. With the segmenting temperatures T_{sp} and T_{sn} known, together with T_h and T_c, we can calculate the effective average thermal conductivities, the effective average electrical resistivities and the effective average Seebeck emf coefficients for the segmented arms using the thermoelectric properties of materials chosen for the segments of the arm. Formulas for the average effective quantities for the doubly segmented arms over the temperature range T_h to T_c are given as follows:

$$\kappa_p = \frac{\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \, dT}{T_h - T_c} \tag{9}$$

$$\rho_p = \frac{\int_{T_c}^{T_{sp}} \kappa_{2p} \rho_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \rho_{1p} \, dT}{\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \, dT} \tag{10}$$

$$\bar{\alpha}_p = \frac{\int_{T_c}^{T_{sp}} \alpha_{2p} \, dT + \int_{T_{sp}}^{T_h} \alpha_{1p} \, dT}{T_h - T_c} \tag{11}$$

$$\bar{\alpha} = \bar{\alpha}_p + \bar{\alpha}_n \tag{12}$$

Let us also introduce the effective Seebeck emf coefficient α_{eph} (or α_{enh}) at the hot junction, which takes into account the Thomson effect for the doubly segmented arms, by the following equation:

$$\alpha_{eph} = \alpha_{1ph} + \frac{T_{sp} (\alpha_{2sp} - \alpha_{1sp}) \left(\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT \right)}{T_h \left(\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \, dT \right)} - \frac{\int_{T_c}^{T_{sp}} \left(\int_{T_c}^{T} \kappa_{2p} \, dT \right) T \frac{d\alpha_{2p}}{dT} \, dT}{T_h \left(\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \, dT \right)} - \frac{\int_{T_{sp}}^{T_h} \left(\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T} \kappa_{1p} \, dT \right) T \frac{d\alpha_{1p}}{dT} \, dT}{T_h \left(\int_{T_c}^{T_{sp}} \kappa_{2p} \, dT + \int_{T_{sp}}^{T_h} \kappa_{1p} \, dT \right)} \tag{13}$$

$$\alpha_e = \alpha_{eph} + \alpha_{enh} \tag{14}$$

The fraction of the Joule heat which is fed back to the hot junction from the doubly segmented arm is also given by

$$a_{jp} = \frac{\displaystyle\int_{T_c}^{T_{sp}} \left(\int_{T}^{T} \kappa_{2p}\, dT \right) \kappa_{2p}\, \rho_{2p}\, dT + \int_{T_{sp}}^{T_h} \left(\int_{T_c}^{T_{sp}} \kappa_{2p}\, dT + \int_{T_{sp}}^{T} \kappa_{1p}\, dT \right) \kappa_{1p}\, \rho_{1p}\, dT}{\left(\displaystyle\int_{T_c}^{T_{sp}} \kappa_{2p}\, dT + \int_{T_{sp}}^{T_h} \kappa_{1p}\, dT \right) \left(\displaystyle\int_{T_c}^{T_{sp}} \kappa_{2p}\, \rho_{2p}\, dT + \int_{T}^{T_h} \kappa_{1p}\, \rho_{1p}\, dT \right)} \tag{15}$$

Geometry of Segmented or Nonsegmented Arms and the Number of Couples. From available data on hot and cold junction resistivities, we choose L_p and L_n such that the ratio of the sum of the hot- and cold-junction resistivities to the product of average material resistivity times the chosen length, is only a small fraction, say 0.05 to 0.25 for p- and n-type arms. We then calculate the p- and n-type effective average resistivities $\bar{\rho}_{pe}$ and $\bar{\rho}_{ne}$, the effective figure of merit $\bar{z}$ of the thermoelectric couple and the effective fraction of a_{je} of the Joule heat generated in the couple which is fed back at the hot junction

$$\bar{\rho}_{pe} = \bar{\rho}_p + \frac{\rho_{jph} + \rho_{jpc}}{L_p} \tag{16}$$

$$\bar{z} = \left(\frac{\bar{\alpha}}{\sqrt{\bar{\kappa}_p\, \bar{\rho}_{pe}} + \sqrt{\bar{\kappa}_n\, \bar{\rho}_{ne}}} \right)^2 \tag{17}$$

$$a_{je} = \frac{\left(a_{jp}\, \bar{f}_p + \dfrac{\rho_{jph}}{L_p} \right) \sqrt{\dfrac{\bar{\kappa}_p}{\bar{\rho}_{pe}}} + \left(a_{jn}\, \bar{\rho}_n + \dfrac{\rho_{jnh}}{L_n} \right) \sqrt{\dfrac{\bar{\kappa}_n}{\bar{\rho}_{ne}}}}{\sqrt{\bar{\kappa}_p\, \bar{\rho}_{pe}} + \sqrt{\bar{\kappa}_n\, \bar{\rho}_{ne}}} \tag{18}$$

To design for maximum efficiency, we calculate the optimum ratio M of the external load resistance to internal generator resistance using the following equation:

$$M = \sqrt{1 + \bar{z} \left[T_h \frac{\alpha_e}{\bar{\alpha}} - a_{je}\, (T_h - T_c) \right]} \tag{19}$$

From the specified terminal voltage V_t, the optimum resistance ratio M and the effective total Seebeck emf coefficient $\bar{\alpha}$ over the over-all temperature range $T_h - T_c$, we calculate the number of couples for optimum efficiency design N_{opt}.

$$N_{opt} = \frac{V_t\, (M + 1)}{M\, \bar{\alpha}\, (T_h - T_c)} \tag{20}$$

From the chosen length of arm L_p or L_n, the effective resistivities $\bar{\rho}_{pe}$ or $\bar{\rho}_{ne}$, the effective thermal conductivities $\bar{\kappa}_p$ or $\bar{\kappa}_n$, the effective total Seebeck emf coefficient $\bar{\alpha}$ over the temperature difference $T_h - T_c$ and the specified output current I, we can now calculate the arm area A_p (or A_n)

$$A_p = \frac{L_p\, \bar{\rho}_{pe}\, (M + 1)\, I}{\bar{\alpha}\, (T_h - T_c)} \left(1 + \sqrt{\frac{\bar{\kappa}_n\, \bar{\rho}_{ne}}{\bar{\kappa}_p\, \bar{\rho}_{pe}}} \right) \tag{21}$$

To wind up the design of the geometry of the arms, we calculate the lengths of the first and second segments of doubly segmented p- or n-type arms using the following expressions:

$$L_{p1} = L_p \frac{\displaystyle\int_{T_{sp}}^{T_h} \kappa_{1p}\, dT}{\displaystyle\int_{T_c}^{T_{sp}} \kappa_{2p}\, dT + \int_{T_{sp}}^{T_h} \kappa_{1p}\, dT}$$

$$L_{p2} = L_p - L_{p1} \tag{22}$$

This synthesis procedure just outlined would yield maximum efficiency at the optimum load which is given by the following expression:

$$\eta_{opt} = \frac{T_h - T_c}{T_h} \frac{M - 1}{\dfrac{\alpha_e}{\bar{\alpha}}\, M + \left(\dfrac{\alpha_e}{\bar{\alpha}} - 2\, a_{je} \right) + 2\, a_{je}\, \dfrac{T_c}{T_h}} \tag{23}$$

The input power Q_{in} per thermoelectric couple is

$$Q_{in} = T_h \alpha_e\, I + K\, (T_h - T_c) - a_{je}\, I^2 r \tag{24}$$

where α_e is an effective Seebeck emf coefficient for the thermoelectric couple at the hot junction and which includes the Thomson effect as defined before in equation 6 or equation 14, where K is the thermal conductance of the thermoelectric couple, where r is its effective electrical resistance, and where the following relationships hold:

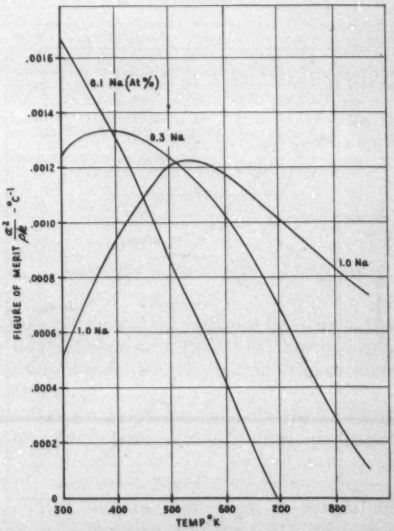


Fig. 6. Figure of merit vs. temperature for p-type PbTe.

$$K = \left(\frac{A_p}{L_p}\bar{\kappa}_p + \frac{A_n}{L_n}\bar{\kappa}_n\right) \tag{25}$$

$$r = \frac{L_p}{A_p}\bar{\rho}_{pe} + \frac{L_n}{A_n}\bar{\rho}_{ne} \tag{26}$$

$$\frac{L_p}{A_p}\frac{A_n}{L_n} = \sqrt{\frac{\bar{\kappa}_p\,\bar{\rho}_{ne}}{\bar{\rho}_{pe}\,\bar{\kappa}_n}} \tag{27}$$

If maximum efficiency is not the primary consideration in the design of the thermoelectric generator but rather the maximum power density, then one would design from a maximum power output criteria point of view and the following equations for the number N_m of thermoelectric couples and area A_p (or A_n) of the p-type and n-type thermoelectric arms, should be used.

$$N_m = \frac{2V_l}{\bar{\alpha}\,(T_h - T_c)} \tag{28}$$

$$A_p = \frac{2\,L_p\,\bar{\rho}_{pe}\,I}{\bar{\gamma}\,(T_h - T_c)}\left(1 + \sqrt{\frac{\bar{\kappa}_n\,\bar{\rho}_{ne}}{\bar{\kappa}_p\,\bar{\rho}_{pe}}}\right) \tag{29}$$

In this case, the conversion efficiency of the thermoelectric couple is given by

$$\eta_M = \frac{T_h - T_c}{T_h}\,\frac{1}{2\,\dfrac{\alpha_e}{\bar{\alpha}} + \dfrac{4}{\bar{z}\,T_h} - a_{je}\left(1 + \dfrac{T_c}{T_h}\right)} \tag{30}$$

CONCLUSIONS

A SYSTEMATIC PROCEDURE has been presented whereby the geometry of the p-type and n-type nonsegmented or segmented arms of a thermoelectric couple and the number of the necessary couples can be determined to yield a given, required performance of a thermoelectric generator for a specified temperature difference. We did so requiring only the knowledge of the thermoelectric properties of a given set of materials available, namely the thermal conductivities, the electrical resistivities, the Seebeck emf coefficients as functions of temperature. We have considered the two most practical cases, the nonsegmented and the doubly segmented arms. The procedure can also be readily extended to the triply segmented arm. However, the small gain in performance resulting from the use of a triply segmented arm does not justify in the majority of cases the cost involved.

In conclusion, it is hoped that this article will help those engineers who are called upon to design a thermoelectric generator to yield a given output for a given heat source and a given heat sink. The design procedure presented takes into account the Thomson effect as well as the variations of the thermoelectric properties of a set of materials with temperature, namely the variation of the thermal conductivities, the electrical resistivities, and Seebeck emf coefficients with temperature. A method is outlined whereby one proceeds from these properties to design the geometry of the thermoelectric couple for optimum efficiency or maximum power and determine the corresponding number of thermoelectric couples necessary to give a desired output voltage and output current when operating under the temperature difference between the heat source and the heat sink.

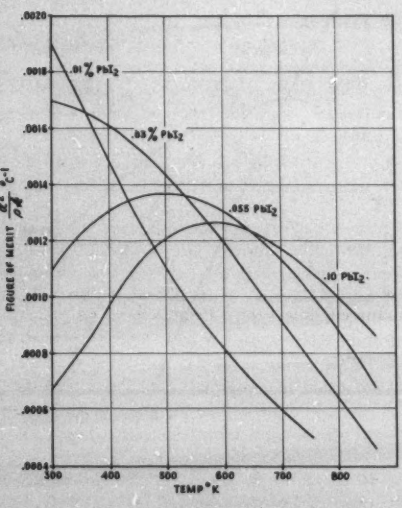


Fig. 7. Figure of merit vs. temperature for n-type PbTe.

Appendix

The synthesis procedure presented here is based on the consideration of each arm of a thermoelectric couple as constituting a conducting rod of constant cross-sectional area which is adiabatically insulated along its length, with one end in thermal contact with a heat source at temperature T_h and the other end in thermal contact with a heat sink at temperature T_c. When a current density J flows through the arm, the differential equation for the temperature distribution in the current-carrying conductor in the presence of a temperature gradient is then derived by using the principle of conservation of energy in any cross section of the arm and is given by the differential equation:

$$\nabla \cdot (\kappa\,\nabla T) + \rho J^2 - \tau J \cdot \nabla T = 0 \tag{31}$$

where

$$\tau = T\,\frac{d\alpha}{dT}$$

or for one dimensional case

$$\frac{d}{dx}\left(\kappa\,\frac{dT}{dx}\right) + \rho J^2 - \tau J\left(\frac{dT}{dx}\right) = 0 \tag{32}$$

A general solution for this equation for the thermal gradients at the hot and cold ends was derived by Burshtein,[2] who first considered the influence of each of the electrical effects alone on the thermal conduction process and then assumed that the interaction of the

electrical effects involves higher-order terms which may be neglected. By including the Peltier effect at the hot and cold junctions, respectively, the expressions for the input heat rate Q_{in} and the heat rejection Q_{rej} are obtained:

$$Q_{in} = \alpha_h T_h I + \frac{A}{L}\int_{T_c}^{T_h} \kappa\, dT - I^2 \frac{L}{A}\frac{\int_{T_c}^{T_h}\left(\int_{T_c}^{T} \kappa\, dT\right)\rho\kappa\, dT}{\left(\int_{T_c}^{T_h} \kappa\, dT\right)^2} - I\frac{\int_{T_c}^{T_h}\left(\int_{T_c}^{T} \kappa\, dT\right)\tau\, dT}{\int_{T_c}^{T} \kappa\, dT} \tag{33}$$

$$Q_{rej} = \alpha_c T_c I + \frac{A}{L}\int_{T_c}^{T_h} \kappa\, dT + I^2 \frac{L}{A}\frac{\int_{T_c}^{T_h}\left(\int_{T_c}^{T} \rho\kappa\, dT\right)\kappa\, dT}{\left(\int_{T_c}^{T_h} \kappa\, dT\right)^2} + I\frac{\int_{T_c}^{T_h}\left(\int_{T_c}^{T} \tau\, dT\right)\kappa\, dT}{\int_{T_c}^{T_h} \kappa\, dT} \tag{34}$$

We next extend the solution of Burshtein for the temperature gradients to the segmented-arms case, and with the Peltier effects taken into consideration, we obtain the following expressions:

$$Q_{c1} = I\alpha_{1h} T_h + \frac{A}{L_1}\int_{T_s}^{T_h} \kappa_1\, dT - I^2 \frac{L_1}{A}\frac{\int_{T_s}^{T_h}\left(\int_{T_s}^{T} \kappa_1\, dT\right)\rho_1\kappa_1\, dT}{\left(\int_{T_s}^{T_h} \kappa_1\, dT\right)^2} - I\frac{\int_{T_s}^{T_h}\left(\int_{T_s}^{T} \kappa_1\, dT\right) T\frac{d\alpha_1}{dT}\, dT}{\int_{T_s}^{T_h} \kappa_1\, dT} \tag{35}$$

$$Q_{r1} = I\alpha_{1s} T_s + \frac{A}{L_1}\int_{T}^{T_h} \kappa_1\, dT + I^2 \frac{L_1}{A}\frac{\int_{T_s}^{T_h}\left(\int_{T_s}^{T} \rho_1\kappa_1\, dT\right)\kappa_1\, dT}{\left(\int_{T_s}^{T_h} \kappa_1\, dT\right)^2} + I\frac{\int_{T_s}^{T_h}\left(\int_{T_s}^{T} T\frac{d\alpha_1}{dT}\, dT\right)\kappa_1\, dT}{\int_{T_s}^{T_h} \kappa_1\, dT} \tag{36}$$

$$Q_{c2} = I\alpha_{2s} T_s + \frac{A}{L_2}\int_{T_c}^{T_s} \kappa_2\, dT - I^2 \frac{L_2}{A}\frac{\int_{T_c}^{T_s}\left(\int_{T_c}^{T} \kappa_2\, dT\right)\rho_2\kappa_2\, dT}{\left(\int_{T_c}^{T_s} \kappa_2\, dT\right)^2} - I\frac{\int_{T_c}^{T_s}\left(\int_{T_c}^{T} \kappa_2\, dT\right) T\frac{d\alpha_2}{dT}\, dT}{\int_{T_c}^{T_s} \kappa_2\, dT} \tag{37}$$

$$Q_{r2} = I\alpha_{2c} T_c + \frac{A}{L_2}\int_{T_c}^{T_s} \kappa_2\, dT + I^2 \frac{L_2}{A}\frac{\int_{T_c}^{T_s}\left(\int_{T_c}^{T} \rho_2\kappa_2\, dT\right)\kappa_2\, dT}{\left(\int_{T_c}^{T_s} \kappa_2\, dT\right)^2} + I\frac{\int_{T_c}^{T_s}\left(\int_{T_c}^{T} T\frac{d\alpha_2}{dT}\, dT\right)\kappa_2\, dT}{\int_{T_c}^{T_s} \kappa_2\, dT} \tag{38}$$

From these expressions and taking into account the effect of junction resistivities, one can then obtain the expressions for maximum efficiency at optimum load and the optimum load to internal resistance ratio M following similar procedure to that given by Ioffe,[3] hence the expressions for the effective thermoelectric quantities for the over-all temperature range and for the given materials, and hence the outlined synthesis procedure.

REFERENCES

1. Electric Analog of the Transport Phenomena in a Thermoelectric Generator, M. E. Talaat. *Proceedings*, American Nuclear Society Symposium on Direct Conversion of Nuclear Energy, Pittsburgh, Pa., March 19, 1960.

2. An Investigation of the Steady-State Heat Flow Through a Current-Carrying Conductor, A. I. Burshtein. *Soviet Physics—Technical Physics*, New York, N. Y., vol. 2, no. 7, 1958, p. 1397.

3. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. F. Ioffe. Infosearch Ltd., London, England, 1957.

Giant EHV Bushing

A huge, 650-kv bushing, designed by General Electric Company engineers for a Project EHV (extra-high voltage) power transformer, has successfully passed all design tests, many of which were performed in the company's high-voltage laboratory at Pittsfield, Mass.

Three of these units will be mounted on a 40,000-kva power transformer soon to be installed at the project's northern substation. Believed to be the largest and highest-rated bushing ever built, it weighs 10,000 pounds, is 28 feet long, and has a BIL (basic impulse insulation level) rating of 2,050 kv.

THERMOELECTRICITY

Design of a 100-Watt Thermoelectric Generator

T. M. CORRY
ASSOCIATE MEMBER AIEE

W. C. MORELAND

E. L. STRICKLAND

An attempt to illustrate the practical problems encountered in utilizing thermoelectric materials now available to construct a 100-watt, free-convection-cooled thermoelectric generator for the U. S. Air Force.

IN the present state of the art, the construction of useful thermoelectric generators requires careful planning on the part of the design engineer. He must be aware of the significant factors that influence the performance, reliability, life, and ease of fabrication of the generator.

Design and construction techniques are described that were employed to produce an experimental 100-watt, free-convection-cooled thermoelectric generator for the U. S. Air Force and two similar demonstration units. These units are shown in Fig. 1. Many of the techniques described have been employed to design experimental generators for use as electric power sources in heating units, hot water heaters, and cooking utensils. In addition, generators have been built that convert heat available from radioisotopes, nuclear reactors, and rocket engines into useful amounts of electric power, but these require a somewhat different design philosophy because of the heat source used.

GENERATOR DESIGN CONCEPT

THE PURPOSE of the 100-watt thermoelectric generator is to convert heat released from the burning of propane gas into electric energy. The important factors to be considered in the design of this generator were the efficiency of energy conversion, size, and weight. When the generator design was in its initial phase, preliminary investigations of weight and size considerations indicated the desirability of operating all the thermal elements at the same hot-junction temperature and the same cold-junction temperature. In order to achieve this condition, the hot core and the heat exchanger must prevent isothermal surfaces to the connecting straps of the thermoelements. An added advantage of this concept is that it allows a single couple to be designed for the generator that can be optimized for these specific hot- and cold-side temperatures.

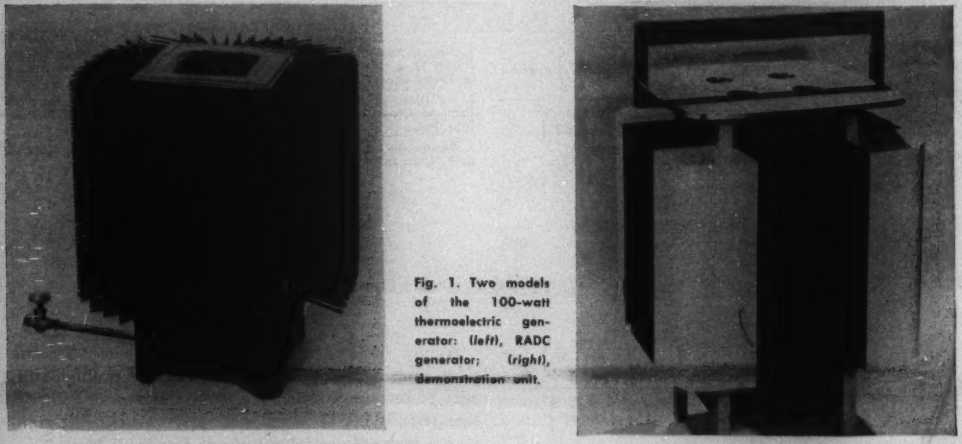


Fig. 1. Two models of the 100-watt thermoelectric generator: (*left*), RADC generator; (*right*), demonstration unit.

In order to minimize size and weight without undue sacrifice in efficiency, it can be seen that careful matching of the three basic elements of the generator must

A special article recommended for publication by the AIEE Solid State Devices Committee.

T. M. Corry and W. C. Moreland are with Westinghouse Electric Corporation, Pittsburgh, Pa.; E. L. Strickland is with the Rome Air Development Center, ARDC, U. S. Air Force, Griffiss Air Force Base, N.Y.

The authors gratefully acknowledge the assistance given by J. Briggs, Rome Air Development Center, and E. J. Duckett, Westinghouse, during technical discussions.

be accomplished. These are the cold-side heat exchanger, the thermoelectric couple, and the heat source which includes the burners, combustion chamber, thermal diffusers, and hot core. The dissipation per unit area of the heat exchanger basically determines the size of a convective cooled generator. The heat exchanger area required can be readily calculated from the estimated efficiency of the couples to be used and the generator power output required. Thus, an estimate of the outer area of the generator is obtained. Next, a couple size is estimated (power output of the couple is basically a function of the geometry or shape of the couple) which may be easily fabricated and which fits easily into the confines of the volume determined by the heat exchanger area. The available hot-core area may then be calculated. Once a geometry for the generator is determined, this process may be reiterated and a fairly well-optimized design obtained.

For this generator a rectangular geometry rather than cylindrical geometry was chosen because it presented fewer problems in construction and assembly. Thus, the hot core was a 4-sided rectangular duct whose hollow center served as the combustion chamber. The hot straps of the couples butt up against the insulated faces of the core. Flexible leads with concentric springs are attached to the cold ends of the couples and flat metal straps are used as electrical leads to form a thermoelectric ladder assembly similar to that shown in Fig. 2. The flat surfaces of the heat exchangers which are also insulated are used to compress the ladder and force the straps of the couples against the core on the hot side and the heat exchanger on the cold side to obtain good thermal contact. Thin insulating matrices are used on both the hot and cold sides to hold the straps in position.

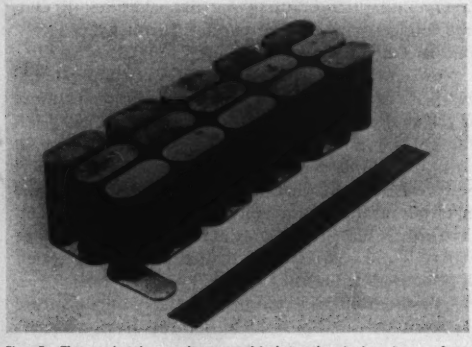


Fig. 2. Thermoelectric couples assembled in electrical series to form ladder.

The basic components of the generator assembly are shown in Fig. 3. The frame serves to tie the heat exchangers together and also gives them added strength. The thermoelectric ladders position and hold the core

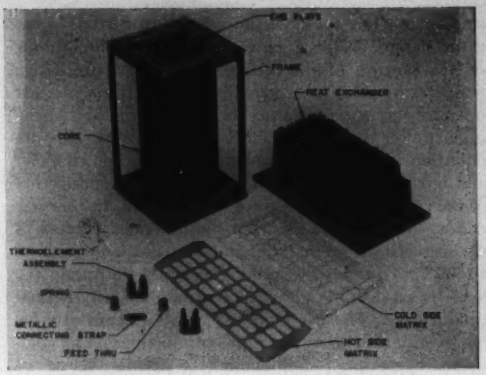


Fig. 3. Component parts of 100-watt thermoelectric generator.

relative to the heat exchangers. The end plates only support the core during assembly and provide end seals on the generator. The flexibility of the ladder and end plates permits the generator to expand and contract under heat cycling without causing permanent distortion or permitting severe stresses to occur in the thermoelectric elements.

In any design of a thermoelectric generator certain other factors must also be considered and investigated to evaluate the design properly. One is the magnitude of the heat leak between the core and the cold side exchangers. To reduce leakage any supporting structure between the core and the cold side must present a relatively high thermal impedance. In this design, the end plates are not structural members and are made of thin stainless steel sheet. In addition, the couples should be spaced quite close together and a good thermal insulation packed between the couples to reduce the heat leak. The percentage of core area covered by couples in this design is approximately 63%. A further problem encountered in designs is the excessive thermal drops which occur between the couple straps and both the core and the heat exchangers at high thermal flux levels. This reduces the available temperature drop across the couples and both the efficiency and power output of the generator.

Another requirement that requires close attention is that of hermetic sealing. Since thermoelectric materials and their contacts are degraded when operated in air, the couples must be either operated in a controlled atmosphere or encapsulated. It should be apparent for most geometries that the generator sealing requirement compounds the heat leak problem because a seal is required between the core and heat exchangers. The end plates discussed previously perform this function in this generator in conjunction with gasket seals between the frame and the heat exchanger.

Obtaining isothermal temperature distribution on the core and heat exchangers is also an important requirement. The degradation in couple lifetime as the temperature increases places a restriction on design

similar to "hot spot" considerations in electric apparatus design. With a poor temperature distribution, only a portion of the core is operating at its design temperature and, as a consequence, many couples are operating at a temperature below that of their maximum power output and efficiency. Obtaining this distribution is basically a problem in combustion chamber and burner design. However, the thermal conductance of the core can greatly reduce this problem. In this generator, the core is made from stainless steel because of the strength of the material and its corrosion resistance at 600 C. To reduce weight, a relatively thin plate (⅛ inch) is used. This gives an undesirably low thermal conductance. The use of other metals is currently being investigated to improve the conductance. The cold-side temperature is low enough to permit the use of aluminum and the mechanical requiremcnts yield a plate thickness of approximately ¼ inch. With the high thermal conductivity of aluminum, obtaining a satisfactory temperature distribution on the cold side is not as difficult a problem.

COLD SIDE HEAT EXCHANGER

If it is assumed that the generator efficiency will be 4 to 5% at 100 watts output, the heat exchanger would have to dissipate from 2,000 to 2,500 watts at a temperature of 150 C. Since the generator was to be designed for minimum size and weight, a free convection heat exchanger had to be developed that could dissipate the highest possible watts per unit weight and watts per unit area of base plate within reasonable occupied volume. Several basic types of extended-surface exchangers were constructed and tested in an attempt to optimize the power dissipating capabilities. These included straight solid-fin types, round-pin types, and rectangular-pin types.

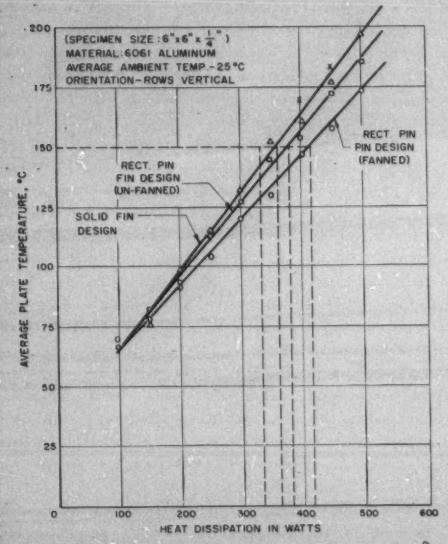


Fig. 4. Performance curves of several extended surface heat exchangers.

The testing was performed by bolting sample exchangers to the face of a heater which was insulated on the remaining sides. The average temperature of the heat exchanger was then measured and plotted as a function of input power; results are given in Fig. 4 for several specimens. Both the length and pitch of the pins and fins were varied; the relative orientation of the rows with respect to the vertical were varied in 45° increments; fanned and unfanned exchangers were tested for the pin fins; and anodized and untreated samples were tested. Fig. 4 shows that a fanned pin design exchanger had the best heat dissipating capability and could dissipate 16.6 watts per ounce and 11.5 watts per square inch of base plate area at 150 C. This heat exchanger then determined the size of the thermoelectric generator. If the generator were 4% efficient, then the required surface area of the heat exchanger base plate would be approximately 218 square inches.

In this generator the heat flux density at the core matches the heat flux density required by the couple assembly. But since the heat exchanger base plate extends out horizontally about 1 inch wider than the core on each side, the effective heat flux density of the heat exchanger will be somewhat less than that appearing on the core. Whereas the heat exchanger had an average heat flux density of 11.5 watts per square inch, the core flux density was approximately 14 watts per square inch.

COUPLE DESIGN AND DEVELOPMENT

The actual design of a thermoelectric couple must be closely related to the characteristics and performance requirement of the generator being designed. Specifically, the following major factors must be considered: (a) Operating temperatures—hot and cold sides; (b) Output voltage; (c) Power output and thermal flux levels; and (d) Efficiency.

Now one of the basic philosophies of couple design has been to operate at as high a hot-side temperature as the state of the art in both thermoelectric materials and generator fabrication will allow. This is done in order to achieve the highest possible Carnot efficiency; however, the somewhat lower figures of merit of the materials available for the higher temperatures and the shorter life presently exhibited by many of these materials and contacts have limited practical operation of generators at present to the 650 to 600 C range.

A further limitation imposed on the hot temperature for fossil-fuel fired generators is the reduction in efficiency of heat transfer from the burner to the core which occurs as the hot-side temperature is increased. This is due to the high exhaust losses that occur in a simple system which does not attempt to utilize any of the available heat content of the exhaust. A compromise should therefore be made in the choice of the hot-side temperature which optimizes the over-all efficiency of the generator. The specific value for this temperature

can only be determined after extensive tests on burner and couple performance have been made. For these generators, an operating temperature of approximately 100 C above the optimum value was chosen to demonstrate the feasibility of operation at the 600 C level. This choice incurred an estimated 12 to 18% reduction in over-all efficiency but yielded a great deal of technical information about operation at elevated temperatures. In addition, this generator was intended to yield information which could be used in the design of an isotopic fueled generator where, of course, combustion efficiency considerations do not apply.

The cold-side temperature is basically determined by the couple efficiency and the cold-side heat exchanger performance, which was discussed in the preceding section. Initial estimates indicated that operation somewhere between 120 and 180 C would yield a fairly well-optimized design for this generator.

The use of fused or soldered contacts to the thermoelectric materials was also a basic concept in couple design. The reason for this is threefold:

1. Lower contact resistances and longer contact life should be obtainable with these techniques than with pressure contacts.
2. Smaller and lighter generators can be designed because of the reduced mechanical strength requirements needed when no pressure contacts are used. (Spring-loaded couples are used in this generator design to provide thermal contact between the couple straps and heat source and sink. These forces are only one quarter that generally used for obtaining electrical pressure contacts.)
3. Complete couples may be fabricated and tested as subassemblies before insertion in the generator which permits a closer quality control of the element and facilitates the assembly of the elements in the generator.

A number of thermoelectric materials were initially considered for this couple. The materials were chosen for their figures of merit over the temperature interval being considered (approximately 600 to 150 C.) For the p-leg, only germanium telluride and zinc antimonide were considered. The ZnSb has a considerably higher figure of merit but is limited by its melting point which is 525 C. Consequently, the p-leg was segmented; the GeTe being operated from 600 to 450 C and the ZnSb from 450 to 150 C. A scale drawing of the final couple is shown in Fig. 5.

Indium arsenide phosphide, indium antimonide, n-type bismuth telluride, and lead telluride were investigated as possible elements for the n-leg. The figure of merit of InAsP and InSb did not prove as high as the PbTe composition which was investigated later in the program. The n-type BiTe has a better figure of merit than the PbTe only in the low temperature range. Estimates of the added contact resistance and additional complexity in assembly indicated that segmenting the n-leg with BiTe was not warranted for the small possible gain in efficiency obtainable.

The voltage obtainable from a couple is determined by the hot and cold operating temperatures and the choice of thermoelectric materials. In the efficiency range currently realized with thermoelectric materials, operation at maximum power transfer or at maximum efficiency is practically equivalent so that thermoelectric couples usually yield approximately half their open-circuit voltage when loaded. On this basis, it was determined that approximately 140 couples would be needed to obtain a nominal 12-volt system under load.

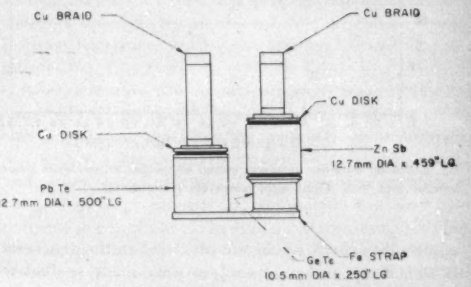


Fig. 5. Sketch of thermoelectric couple used in generators.

In order to make certain that the 100-watt output would be obtained, it was decided to build the couple for a nominal 1-watt output. The actual design value for this couple was closer to 1.3-watts output, but previous test work indicated that variations in material properties, contact resistance, and other practical factors reduced actual couple performance below the theoretical value. These preceding requirements established the couple geometry. The specific size of the couple was determined by the requirements imposed by the cold-side heat exchanger and the hot core.

COUPLE TESTING AND PERFORMANCE

TESTS OF THE COUPLE DESIGN were made in a controlled atmosphere with 600 C on the hot side and 150 C at the cold side. The purpose of these tests was twofold: to determine if the life of the couples was satisfactory and to provide a means of evaluating couples for use in the generator. After the initial tests, some modifications in contact materials and geometry were made and a new design specified. About 20 couples of this design were tested for 100 hours under the conditions indicated. Several were operated for sustained periods with a 650 C hot side to make sure that the couples would not rapidly deteriorate in the event that the hot temperature exceeded the 600 C level. Thermal cycling tests were also performed and the couple was found to be satisfactory.

Fig. 6 is a scatter diagram of the output at maximum power transfer for the sample couples tested against their room temperature resistance. The apparent correlation of this parameter with cold resistance was used

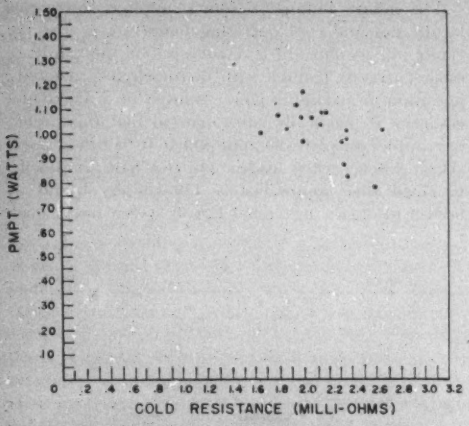


Fig. 6. Scatter diagram of power output of couples at maximum power transfer and their initial room temperature resistance.

as a quality check on the couples used in the generator. A sufficient number of couples were made so that by selection, only couples having initial resistances less than 2.3 milliohms were used in the generator. Thus, a nominal output of 1 watt or better was expected from each couple. The measured efficiency of the couple was approximately 6 to 6.5%.

Although the tests carried out in a controlled atmosphere without insulation indicated that the life of the couples was satisfactory at 600 C, previous experience indicated that tests should be performed in which the couples were operated under simulated generator conditions in the presence of the thermal insulation to be used in the generator. In addition, it was felt advisable to evaluate electrical and thermal insulations which were to be used in the generator and estimate the thermal drops. As a consequence, small test modules were built which contained 5 couples each. These tests indicated that the insulation should be separated from the thermoelectric material. Tests were then performed using Sauereisen cement and also flake mica with a silicate binder as couple coatings. Both appeared to be reasonably satisfactory; but, since Sauereisen is more convenient to handle and apply, it was selected for use in the final design of the generator.

During the module tests, it was also found that none of the glass enamel coatings which were tried as electrical insulation on the hot side could be used in direct contact with the couples and thermal insulation. However, several glass enamels were found to be satisfactory when a thin piece of mica paper was used between the core coating and the couple hot straps. The final glass used on the core was a refractory enamel. On the cold side, anodizing was used in conjunction with a thin piece of mica paper for electrical insulation; thermally conducting paste minimized the thermal drop. An exploded silica mixed with acetylene black was used as thermal insulation between the couples because it appeared to be somewhat less reactive than the other thermal insulations investigated and had acceptable insulating qualities. Two modules with this particular combination of coating and insulation were tested and the results indicated that the power output would not be quite as high as predicted from individual couple test data. However, the output level showed that 100 watts could be obtained with 140 of the 1-watt couples described previously in this article.

HEAT SOURCE DEVELOPMENT

Fossil-fuel fired thermoelectric generators require heat sources capable of transferring thermal energy to the thermoelements with high efficiency. The efficiency of heat transfer is a function of the burner design, the heat transfer mechanisms, the heat-flux density required for the thermoelements, the flame temperature, and the temperature of the hot side of the generator. With conventional fuel burners, it is difficult to meet all the requirements that make the energy source compatible with the generator. These requirements are: large component of radiant heat transfer for high efficiency and small size; uniform duct or hot-side temperatures for maximum utilization of the power conversion capabilities of the thermoelectric materials; and high heat-flux density for minimum generator size.

For the 100-watt generator, the heat exchanger, the thermocouple performance, and the generator geometry determined to a large extent the performance requirements of the burner system. The required characteristics of the burner system were analyzed to be as follows: (a) Combustion chamber size 4 by 4 by 11 inches duct; (b) Duct temperature 600 C ±20 C; (c) Heat flux density approximately 14 watts per square inch of duct surface area; (d) Heat required by the generator approximately 2,500 watts or 8,500 Btu per hour; (e) Efficiency of heat transfer from the burner to the generator core greater than 60%; and (f) Minimum possible weight.

Six burner systems were designed, constructed, and tested during the program. Most of the systems studied were potentially useful but required considerable additional development effort before they could be considered practical for the 100-watt generator. The burner system selected is relatively lightweight, easy to fabricate, and efficient. However, it has been found that while it is possible to achieve excellent performance once the combustion screen has been properly adjusted, slight changes in screen position or geometry will degrade performance.

The 100-watt generator heat source is a high-energy density incandescent combustion system that permits the design and construction of compact thermoelectric generators. It consists of an assembly of four gas burners, a metal screen assembly, and a duct. The principles of operation are as follows:

1. The fuel burners serve to release the energy of the fuel in the form of incandescent flames or gases. Heated primary and secondary air and the products of

combustion then tend to form an inverted incandescent cone at the head of each burner with a hot core of gas forming at the tips of the cones. Without the metal screen assembly, the hot column of gas would tend to stay at the center of the duct and most of the energy would escape as stack losses.

2. The metal screen assembly serves to:
   a. Absorb energy from the incandescent flame and hot gases by radiation and convection. At any given temperature, a body which is a good absorber of radiation is also a correspondingly good radiator. Thus, the screen serves as a radiant source of energy that transfers energy to the walls of the duct.
   b. Break-up the hot core of gases by forcing the flow pattern to form adjacent to the duct walls. Heat transfer to the walls by convection is enhanced because the temperature of the gas adjacent to the walls is increased and effective mixing between the hot gas and the boundary layer is achieved.
   c. Form a larger incandescent gas volume than would exist when the screen is not present.

3. The metal duct serves as a collector of the thermal energy released by the burners. In this particular system, the duct is made of stainless steel which has been especially treated to raise the absorptivity of the surface (approximately 0.9 as compared to 1.0 for a perfect black body).

4. The burners and screen have been tailored to provide a nearly isothermal surface over the entire duct at the desired surface operating temperature and heat flux.

Fig. 7 is a family of curves showing the relationship between heat flow through the generator core and core temperature for one of the incandescent screen burner designs. In addition, efficiency of heat transfer from the burner to the generator and heat flux density are indicated. Each curve was obtained by holding the propane gas flow constant and varying the thermal loading on the core. Curves were obtained for four rates of fuel consumption.

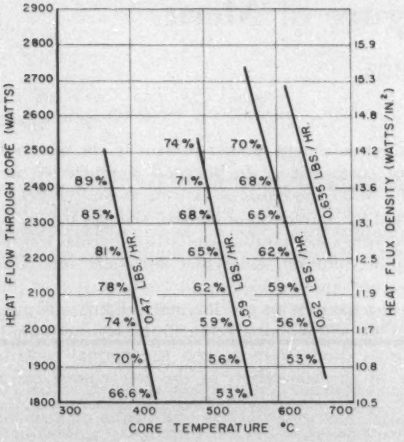


Fig. 7. Plot of thermal flux level vs. core temperature at several fuel rates.

GENERATOR TESTS AND PERFORMANCE

DURING THE FABRICATION of the generators, continual checks were made of the cold resistance of the couples to make certain that no damage was done when the cold straps were soldered to the braids or when the springs and braids were compressed and the heat exchangers applied. No significant change was apparent in these resistances during the various fabricating procedures.

After assembly, the generators were brought up to about 400 C and the thermal distribution on the cores checked. During this time, the generators were pumped out with a vacuum pump to remove the water vapor and other contaminants. The generators were then charged with a mixture of argon-hydrogen and the temperature brought up to give a 100-watt output. This output was obtained with the hottest measured temperature on the cores being approximately 620 C. This gave a comfortable margin as far as maximum temperature is concerned since it is anticipated that there is probably a 40 to 50 C drop from the core to the straps on the thermoelectric elements. Since at this temperature the generators meet the requirements of 100 watts, they were not raised any higher; however, they were heated several times to this level to ascertain that there were no severe detrimental effects caused by thermal cycling. Typical test results for one of the generators are given in Table I.

Table I. Performance Data on Tap-100 Generator.

Internal resistance (cold)	0.34 ohms
Internal resistance (operating temperature)	0.96 ohms
V(open circuit)	19.7 volts
P(at maximum power transfer	102.5 watts
T_h (average of hot core)	582C
T_c (average of cold side exchanger)	154C
Electric power output/fuel input	2.4%
Electric power output/thermal flux through generator	3.7%
Total weight	47 lbs

The open-circuit voltage of the generator was below expectations by about 10%. This is due to the fact that the thermal drops and nonuniformity were greater than expected. However, by operating at a slightly higher temperature and slightly mismatching the load, 100 watts at 12 volts could easily be obtained. If the generator were heated to a uniform 600 C hot-strap temperature, a power output of 120 watts should be obtained. A curve showing the performance of the generator as a function of core temperature is shown in Fig. 8. The power output curve quite closely approximates a parabolic function of the temperature difference across the couple; however, the efficiency falls off from a linear function as the core temperature approaches 600 C.

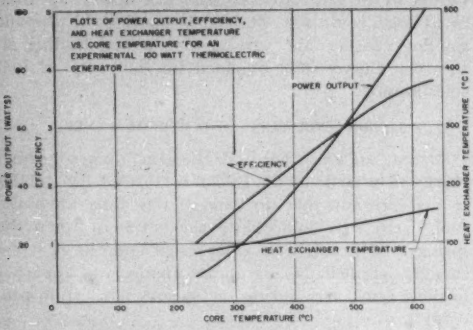

PLOTS OF POWER OUTPUT, EFFICIENCY, AND HEAT EXCHANGER TEMPERATURE VS. CORE TEMPERATURE FOR AN EXPERIMENTAL 100 WATT THERMOELECTRIC GENERATOR
POWER OUTPUT
EFFICIENCY
HEAT EXCHANGER TEMPERATURE
POWER OUTPUT (WATTS)
EFFICIENCY
HEAT EXCHANGER TEMPERATURE (°C)
CORE TEMPERATURE (°C)

Fig. 8. Plot of generator power output and efficiency as a function of core temperature.

CONCLUSION

ONCE A THERMOCOUPLE DESIGN has been finalized, it will have a certain characteristic efficiency that is determined by thermoelement material characteristics, compatibilty between the various materials, contact resistance, the degree to which the design has been optimized, and operating temperatures. However, when operated in a generator, the performance of the thermocouple is degraded by the following factors:

1. Nonuniform temperature distribution on the hot and cold sides of the generator.
2. Temperature drops that appear across the hot and cold thermal contacts of the couple and across the flexible braid.
3. Heat that leaks past the thermocouple through the thermal insulation, the encapsulating material, and the sealing plates.

In the present state of the art the cumulative effect of the above factors can lower the effective efficiency of a thermocouple 10 to 22% in a well-designed generator. In addition, if high-temperature generators are not properly sealed and do not contain the proper inert or reducing gas, useful life can be considerably shortened. However, despite these difficulties, many practical thermoelectric generators have been built and used in military and industrial applications.

THERMOELECTRICITY

Theoretical Bound on the Thermoelectric Figure of Merit

F. J. DONAHOE

An attempt to determine the upper theoretical limit of the well-known materials parameter, the figure of merit z.

THE figure of merit $z = S^2\sigma/\kappa$ is a well known materials parameter which is a measure of the relative effectiveness of the material when used as an active element of a thermoelectric device. Other considerations being equal, the best material will have the largest z value. It is thus of considerable practical importance to obtain a reasonable upper bound for z, assuming one exists.

Of the three coefficients which comprise z, two, the Seebeck coefficient S and the electrical conductivity σ, are determined primarily by the density and mobility of the free charge carriers present in the material. The third coefficient κ, the thermal conductivity, depends upon other mechanisms as well as on the heat transported by convection of the free charge carriers. Among these other mechanisms are lattice thermal conduction, exciton diffusion, ambipolar diffusion and radiation. To a first approximation, the contributions of the various mechanisms to the thermal conductivity are additive. We will ignore all contributions other than lattice thermal conductivity κ_g and the normal contribution due to the convection of the free charge carriers κ_e

A special article recommended for publication by the AIEE Solid State Devices Committee.

F. J. Donahoe is with The Franklin Institute, Philadelphia, Pa.

The author wishes to thank the sponsors of the thermoelectric effects research program for their financial support.

which may be equated to $\Lambda\sigma T$, where Λ is the Wiedemann-Franz-Lorenz number, and T is the absolute temperature. Thus

$$\kappa = \kappa_g + \Lambda\,\sigma\,T \tag{1}$$

This approximation is justified for present thermoelectric materials operating at room temperature and below, but would not be correct for materials operating at elevated temperatures.

A typical example of the dependence of the thermal conductivity on the electrical conductivity is shown in Fig. 1. The material here is the alloy semiconductor $Bi_2Te_{2.1}Se_{0.9}$ which has been doped with varying amounts of either cuprous bromide or silver iodide. The expected linear relation between κ and σ is found. Furthermore the slope is in excellent agreement with theoretical prediction, being 2.2 $(k/e)^2T$, where k is the Boltzmann constant and e the magnitude of the electronic charge. Theory predicts $2(k/e)^2T$ for a nondegenerate semiconductor with acoustic scattering. The increase over this value may be attributed to the partial degeneracy of the conduction electrons. At low doping levels the semiconductor is approaching intrinsic conductivity. The excess thermal conductivity in this region is the result of ambipolar diffusion.

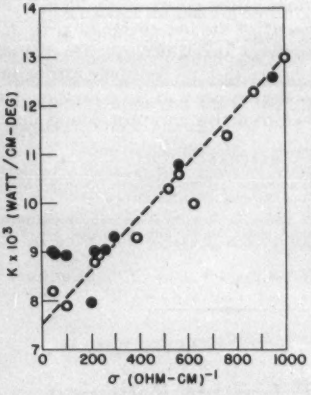


Fig. 1 The relation between electrical and thermal conductivity. Data points are for an alloy $Bi_2Te_{2.1}Se_{0.9}$ doped with cuprous bromide (solid points) or with silver iodide (open points).

There is a second constraint on the variables which enter the figure of merit and this is the relation between the Seebeck coefficient and the electrical conductivity. In an extrinsic semiconductor this relation has the form

$$S = \pm\,\frac{k}{e}\,(B - \ln\,\sigma) \tag{2}$$

where B is a constant if the mobility is independent of the concentration of free charge carriers. The positive sign is used for p-type conductivity and the negative sign for n-type. Fig. 2 shows the agreements with this formula found for the doped $Bi_2Te_{2.1}Se_{0.9}$ alloys. The straight line portion of the graph has the slope k/e. This linear portion terminates on the low σ end when the number of thermally excited minority carriers per unit volume becomes comparable to the number of majority carriers introduced by doping. Inasmuch as the contributions of the two carriers to the Seebeck coefficient have opposite signs, an internal compensation occurs and the absolute value of the Seebeck coefficient is reduced.

As a consequence of these constraints on the independent variation of the three coefficients which comprise the figure of merit z, there exists a particular value of the Seebeck coefficient at which z is a maximum. There are three cases which may be distinguished.

1. The lattice thermal conductivity κ_g is much greater than $\Lambda\sigma T$ throughout the use range of values of σ. If this situation prevails one may ignore the dependence of κ on σ. The maximum value of z occurs at the maximum in $S^2\sigma$. This case has been treated by several authors, in particular by A. F. Joffe.[1] The condition that $\frac{\partial(S^2\sigma)}{\partial\sigma} = 0$ when the relation between S and σ is as given by equation 2 yields the result

$$S = \pm 2(k/e) = \pm 172\ \mu v \text{ per degree} \tag{3}$$

This particular situation is not very interesting, for present thermoelectric materials have lattice thermal conductivities sufficiently small that the variation of κ with σ may not be neglected.

2. The lattice thermal conductivity κ_g is comparable with $\Lambda\sigma T$ throughout the useful range of σ. Considering the restrictions imposed by equations 1 and 2 one finds that $\frac{\partial z}{\partial \sigma} = 0$ when

$$S = \pm 2(k/e)\,(\kappa/\kappa_g) = \pm 172\,(\kappa/\kappa_g)\ \mu v \text{ per degree} \tag{4}$$

The required value of S is greater than that given by equation 3 by the ratio of the total thermal conductivity to the lattice thermal conductivity.

Since the absolute value of S depends on the number density of free charge carriers, equation 4 will be satis-

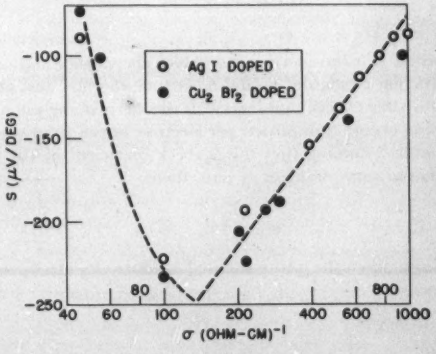


Fig. 2 The relation between Seebeck coefficient and electrical conductivity. Data points are for an alloy $Bi_2Te_{2.1}Se_{0.9}$.

fied only for a particular number density which will be

$$n_o \approx 2(2\pi\, m^*\, k\, T/h^2)^{3/2} \qquad (5)$$

where

m^* = density of states effective mass of the free charge carriers

The actual value of the figure of merit will depend upon three factors: the density of states effective mass m^*; the mobility μ of the free charge carriers, which should both be as large as possible; and the lattice thermal conductivity κ_g which should be small. While there are theoretical arguments linking m^* and μ, the weight of empirical evidence shows these quantities to vary independently within rather wide limits, and of course κ_g is capable of considerable variation independent of m^* and μ. In the present thermoelectric alloys based on bismuth telluride, the mobility of the free charge carriers seems to be limited by crystalline imperfections other than those which are necessarily present to provide the optimum number of charge carriers. Values of the figure of merit of the order of 6×10^{-3} per degree should be found in these materials when these effects which limit the mobility are removed.

3. The lattice thermal conductivity is so small as to be negligible in comparison with the thermal conductivity of the free charge carriers $\Lambda\sigma T$. If values of the lattice thermal conductivity $\leqq 10^{-4}$ watts per cm per degree can be realized in a semiconductor material it may not be possible to satisfy equation 4. Referring to Fig. 2, it is apparent that the absolute value of S is bounded and begins to decrease when the semiconductor becomes intrinsic. If the absolute value of S required by equation 4 is larger than the upper bound of $|S|$, then the maximum figure of merit occurs at this upper bound. P. J. Price[2] has obtained the following equation for the difference between the maximum positive Seebeck coefficient and the minimum negative Seebeck coefficient of the p and n types of the same semiconductor material.

$$S_m^p - S_m^n = \frac{k}{e}\{\alpha^{\frac{1}{2}}(\alpha-2)^{\frac{1}{2}} - \ln|\alpha - 1 + \alpha^{\frac{1}{2}}(\alpha-2)^{\frac{1}{2}}|\} \qquad (6)$$

where α, the energy transported in units of kT, is

$$\alpha = (\epsilon_g/kT) + \delta_1 + \delta_2 \qquad (7)$$

where ϵ_g is the energy gap between the valence and conduction bands and δ_1 and δ_2 include thermal and phonon drag effects; that is $\delta_1 kT$, is the thermal and phonon drag energy transported per electron in the conduction band. Assuming that the Seebeck coefficient of the intrinsic semiconductor is zero, then

$$|S_m^p| = |S_m^n| = \frac{1}{2}(S_m^p - S_m^n) \qquad (8)$$

Since, when the lattice thermal conductivity can be neglected,

$$z = S^2/\Lambda T$$

the upper bound on z may be obtained by substituting from equations 7 and 8 and using the theoretical value for $\Lambda = 2\ (k/e)^2$

$$z_m = \frac{1}{8T}\{\alpha^{\frac{1}{2}}(\alpha-2)^{\frac{1}{2}} - \ln[\alpha - 1 + \alpha^{\frac{1}{2}}(\alpha-2)^{\frac{1}{2}}]\}^2$$

A typical value for the energy gap of a heavy compound semiconductor might be $\epsilon_g \approx 0.16$ev (electron volt); and, since phonon drag effects are ordinarily negligible at room temperature, $\delta_1 \approx \delta_2 \approx 2$. Assuming these values, $\alpha \approx 10$ and $z_m \approx 17 \times 10^{-3}\text{deg}^{-1}$ at $T = 300$ K. Before figures of merit approaching this limit can be achieved, semiconductors with normal Wiedemann-Franz ratios must be available. Starting from present best materials, either an order of magnitude reduction in lattice thermal conductivity, or a tenfold increase in the carrier mobility, or some combination of these is required. Some new mechanisms must be sought to reduce lattice thermal conductivity without decreasing carrier mobility.

CONCLUSION

THE THERMOELECTRIC figure of merit is defined as $z = S^2\sigma/\kappa$. Since the Seebeck coefficient S of an extrinsic semiconductor can be shown to be a linear function of the logarithm of the electrical conductivity σ, while the thermal conductivity κ is a linear function of σ, the figure of merit z will have a maximum at a predictable value of S. The magnitude of z at the maximum will be determined by (a) the mobility of the free charge carriers, μ; (b) the three-hālves power of the density of states effective mass m^* of the free charge carriers; (c) the thermal resistivity of the lattice κ_g^{-1}. On the assumption that the lattice thermal resistivity can be increased to $\geqq 10^4$ cm-degrees per watt, an expression due to P. J. Price is used to derive an upper bound for z.

REFERENCES

1. Semiconductor Thermoelements and Thermoelectric Cooling (book), A. F. Joffe. Infosearch, Ltd., London, England, 1957, p. 49.

2. Theory of Transport Effects in Semiconductors: Thermoelectricity, P. J. Price. *Physical Review*, American Institute of Physics, New York, N. Y., vol. 104, no. 5, Dec. 1, 1956, pp. 1223-39.

"Natural" Gas via Radiation

Columbia University scientists will use a large supply of radioactive cobalt for research in an effort to develop another large source of "natural" gas for the future.

This contribution to fuel technology is only part of a broad program of research in radiation-promoted chemical kinetics, a comparatively new scientific field which holds promise of breakthroughs in many important areas, theoretical as well as applied. In this part of the Columbia research, gamma radiation from Cobalt-60 will be employed in an effort to convert coal char into methane, the major ingredient of natural gas. The research is being financed by a grant from the Consolidated Natural Gas System, a major eastern distribution company.

Short-Circuit Torques in Turbine–Generators

P. I. NIPPES
MEMBER AIEE

THE PROBLEM of torsional resonance in turbine–generators is solvable by a number of different methods. Results of the present analysis serve as an approximate, independent check on these solutions. In addition, the effect of changing physical proportions of the unit may be evaluated from the curves.

In all engineering problems it is desirable to have an independent check on solutions. This is particularly true of problems of this type, which relate to heavy machinery. Here the result must be reliable and it is usually not possible to perform a test on the system itself for comparison with the solution.

From a group of studies, using a generalized driving torque,

$$T = 0.3\epsilon^{-\alpha t} + \epsilon^{-\beta t} \sin \omega t - 0.5\epsilon^{-\gamma t} \sin 2\omega t$$

the solid curve of Fig. 1 was drawn. The dashed curve is a plot of the solution using the driving torque:

$$T = \sin \omega t - 0.5 \sin 2\omega t$$

A comparison of the effect of the direct term may be noted at lower values of f_{12} and causes the solid curve to be slightly above the dashed one. The effect of decay factors is noted at f_{12} values near resonance where times to peak are greatest and where the solid curve lies below the dashed one. The curve of time to peak is given in Fig. 2. From this it may be realized that even though modern breakers and relays clear faults in 5 to 8 cycles, peak shaft torques usually occur prior to breaker opening.

As an example demonstrating the use of this curve,

Machine data: $X_d = 0.12$, $E = 1.05$, $T_n = 3,000$ pound-feet, $f = 39$, $J_1/J_2 = 2.5$, $d = 7$ inches

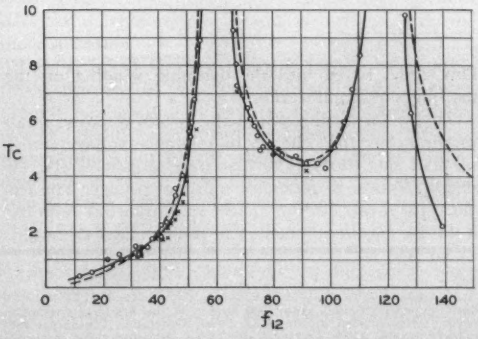


Fig. 1. Maximum peak shaft torque for the system with a single degree of freedom.

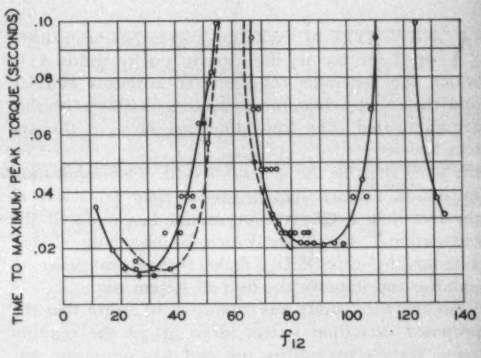


Fig. 2. Time to maximum peak shaft torque.

From Fig. 1, $T_c = 1.9$, $T_{12} = \dfrac{T_c E^2 T_n}{X_d''(1 + J_1/J_2)} = \dfrac{1.9\,(1.05)^2(3,000)}{0.12(1 + 2.5)}$

$= 14,900$ pound-feet

The related peak shaft stress is

$$\tau = \frac{16T}{d^3} = \frac{192(14,900)}{(7)^3} = 8,300 \text{ pounds per square inch}$$

where

X_d'' = generator subtransient reactance, per unit
E = generator internal voltage behind subtransient reactance
T_n = torque in shaft in pound-feet at rated kva. unity power factor
$'$ = calculated natural frequency of shaft and two concentrated masses
J_1 = polar moment of inertia of generator
J_2 = polar moment of inertia of turbine
d = diameter of minimum interconnecting shaft section (usually the journal)

For the problems of 2 and 3 degrees of freedom, the analysis is more complex. The characteristic equations for these systems may be reduced to curves such that the conditions for resonance may be determined easily. These serve two functions:

1. To insure that a unit is designed not to coincide with resonance.

2. To use as a check relation with analog computer solutions, where a frequency dial may be changed to give resonance at the predicted value.

Digest of paper 59-1140, recommended by the AIEE Rotating Machinery Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill., Oct. 11-16, 1959. Published in AIEE *Power Apparatus and Systems*, Feb. 1960, pp. 1677-83.

P. I. Nippes is with the Carrier Corporation, Ridgway, Pa.

The Brushless Excitation System

R. W. FERGUSON
MEMBER AIEE

R. HERBST
ASSOCIATE MEMBER AIEE

R. W. MILLER
ASSOCIATE MEMBER AIEE

A NEW TYPE of excitation system has been developed for use in the electric utility industry in which the generator collector and collector brushes, and the exciter commutator and commutator brushes are eliminated. The basic difference between this system and its predecessors is an a-c exciter mounted on the same shaft as the generator field. This innovation introduces a much shorter exciter time delay due to the fact that a 420-cycle a-c exciter has replaced the conventional d-c exciter which is inherently slower. The smaller time delays make the system easier to stabilize and improve the over-all system response.

An analytical study was conducted to assure that the proposed excitation system meets all of the requirements for electric utility use and has optimum performance characteristics. The primary factors considered were the ability to maintain static regulation of generator voltage, stability of the excitation system performance under all modes of operation, ability to restore voltage rapidly after a transient disturbance, and satisfactory performance when the generator is operating in the region of dynamic stability beyond the static stability limit.

One of the most powerful techniques for investigating a proposed feedback control system is direct simulation on an analog or digital computer. The system discussed here was studied on an electronic differential analyzer using methods previously reported. In previous studies, only limited success could be obtained in the analog representation of the synchronous machine equations because of difficulty in obtaining the sine and cosine of the machine angle. The present study employed diode function generators to produce the sine and cosine functions to a high degree of accuracy, and, since there are no time delays or potentiometer resolution problems associated with these devices, a much improved analog was obtained.

The various performance characteristics were examined in the analog representation by the following tests.

1. The system was observed as the generator reference voltage underwent an instantaneous change in the following modes of operation: (a) no-load; and (b) one per unit load, external impedance of 9.0% and infinite bus voltage of 1.0 per unit.

2. System response was investigated when the infinite bus voltage experienced an instantaneous change. This would be equivalent to the actual system being subjected to a severe change in reactive load.

3. The shaft power was subjected to instantaneous changes. The actual system would not experience a sudden change in shaft power but this severe type of test demonstrated the excellent stability of the system.

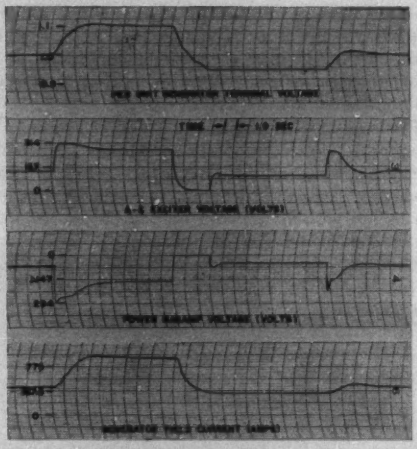


Fig. 1. Step changes in generator reference—full-load rated conditions (X_d 0.09 per unit).

The major damping feedback is usually derived from exciter terminal voltage. Since it was desirable that this signal source would not be required on the rotating rectifier system, it was necessary to investigate the possibility of using signals with some functional dependence upon either generator terminal voltage or power magnetic amplifier output. The results of the computer study indicated that very satisfactory performance could be obtained using the power magnetic amplifier output voltage as modified by a transfer function of the type

$$\frac{G\,T_1 p}{(1+T_1 p)\,(1+T_2 p)}$$

This signal is fed into the damping winding on the first stages of amplification.

Fig. 1 is an oscillogram of the system response to an instantaneous 10% change in reference voltage under full-load conditions. The first trace illustrates the excellent response of generator terminal voltage. The second trace illustrates the almost instantaneous response of the a-c exciter to changes in power magnetic amplifier voltage.

Digest of paper 59-1108, "Analytical Studies of the Brushless Excitation System," recommended by the AIEE Power Generation Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill., Oct. 11-16, 1959. Published in AIEE *Power Apparatus and Systems*, Feb. 1960 pp. 1815-21

R. W. Ferguson, R. Herbst, and R. W. Miller are with the Westinghouse Electric Corp., East Pittsburgh, Pa.

System Planning Production Cost Calculations

K. M. DALE
MEMBER AIEE

C. H. HOFFMAN
MEMBER AIEE

W. H. FERGUSON
MEMBER AIEE

J. A. ROSE
ASSOCIATE MEMBER AIEE

A METHOD of electric energy production cost calculation has been developed for use in the solution of a simulation problem by digital computers. Several new features have been incorporated to improve the flexibility as compared to previous methods without sacrificing accuracy. It constitutes one phase of a comprehensive system planning study which evaluates cost differences due to variations in types of peaking units, spinning reserve policies, unit outage rates, and use of pumped-storage hydro, as well as unit size, heat rate, location, etc.

The basic calculation is an improved version of the commonly used load-duration curve method in which the energy-producing units are stacked up to fill the area under the load-duration curve. Short load periods are used to increase the representation accuracy of seasonal variations in maintenance schedules.

Hydroelectric generation is treated as a reduction of load rather than as equivalent thermal generation. When it is pumped-storage hydro, the energy available in the stored water is used to carry a portion of the peak load, and the energy necessary to refill the pond is generated thermally during the light-load hours as shown in Fig. 1. Due regard is given to pond capacity, unit capability as a generator and as a pump, hours of operation under each condition, and the efficiency of the generation-pumping cycle. The net effect on production cost is to transfer some load from high-cost thermal units to low-cost thermal units.

The effect on cost of spinning reserve is recognized by adding the spinning reserve requirement to the energy, and dispatching enough units to meet the total capacity requirement. The machines are dispatched in a pre-established sequence, generally on the basis of economic priority, but also recognizing area support limitations. The effective capacity of each unit reflects both its actual maximum capacity and its availability during the load period.

Data required for each machine include its position in the priority list, its capacity, its minimum load expressed as a fraction of its capacity, and its operating cost at full load and at minimum load. This information is combined with the capacity and energy requirements in a manner best illustrated by the geometric analog of Fig. 2, to give the time, duration, and cost of operation at each load level. In Fig. 2 the effective capacity of the nth unit is A_nC_n and its minimum load rating is $A_nC_nF_n$. The mid-ordinate of the capacity block intersects the spinning capacity requirement line at h and the energy line at h'. The unit is synchronized a total of h hours, generates at minimum load for $(h\text{-}h')/(1\text{-}F)$ hours, and at full load for $(h'\text{-}F\ h\ )/(1\text{-}F)$ hours. Production costs are summed for all machines, non-

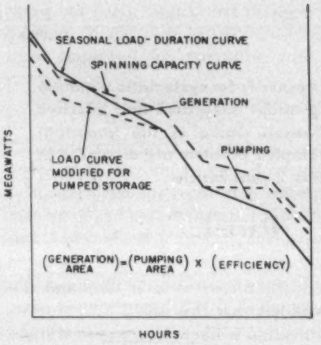


Fig. 1. Load curve modifications.

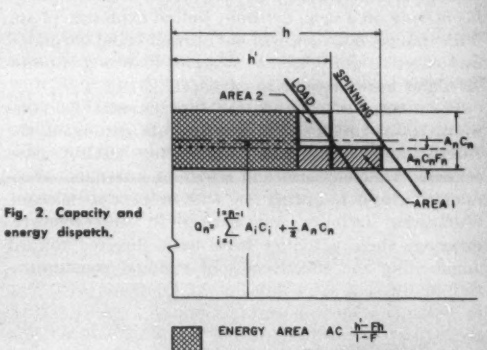


Fig. 2. Capacity and energy dispatch.

energy costs are added, and their total is multiplied by a present-worth factor to recognize the time value of money.

This production cost calculation has been programmed for an IBM-*704* computer. The calculation for a 20-machine system takes about 0.25 second per month. Accuracy comparisons against a true incremental cost dispatch of the same machines for the same loads show a difference which is generally less than 1.0%.

Digest of paper 59-1176, "Production Cost Calculations for System Planning by Operational Gaming Models," recommended by the AIEE Power Generation Committee and the AIEE System Engineering Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill. Published in AIEE *Power Apparatus and Systems*, Feb. 1960, pp. 1746-52.

K. M. Dale and W. H. Ferguson are with Westinghouse Electric Corporation, East Pittsburgh, Pa., C. H. Hoffman and J. A. Rose are with the Public Service Electric and Gas Company, Newark, N. J.

Progress and Problems in World Communication

E. I. GREEN
FELLOW AIEE

There is a great necessity for systematic planning in order to bring about integrated and effective world communication. Some of the important phases of this complex problem are discussed in this 2-part article.

Part I

TODAY, when world affairs seem at sixes and sevens, and we wonder what this world is coming to, world communication is likewise at a critical stage. Change is accelerating; in fact, world communication is entering on a new, dynamic, indeed explosive, phase. This change, however, will not of itself bring integrated and effective world communication. Planning is necessary, and must be done in advance.

For a number of years, the International Telecommunications Union (UIT) and its proficient organs, the International Consultative Committees (CCI's), have rendered valuable service in achieving international cooperation and co-ordination with respect to telecommunication facilities and services. In large measure, however, these activities have been directed toward augmenting the effectiveness of regional communication in different parts of the world. Emphasis needs now to be centered on true world communication, i.e., across oceans and between continents. Thus, we will be concerned here with changes occurring in world communication, new techniques involved, and problems that lie ahead.

STATISTICAL AND HISTORICAL

OF THE VARIOUS FORMS of telecommunication, telephony far exceeds all the rest both in volume and importance. Telephony, then, is where we start. One of the real marvels of the 20th Century has been the growth in telephony. Vast continental networks, complex and fairly well integrated, with myriad interdependent parts, have been built up in Europe and North America, together with smaller but substantial developments in other parts of the world.

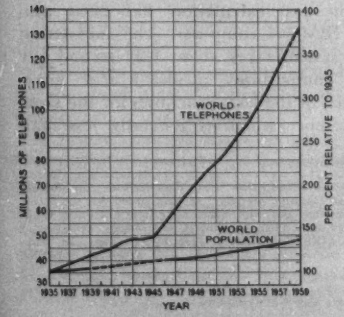


Fig. 1. World telephones and world population.

Evidence of what has happened is found in the number of world telephones (Fig. 1). Notwithstanding the tremendous surge in world population, the number of telephones has grown three times as fast. Since 1935 this number has multiplied nearly fourfold, today's total being about 135 million. Automation has grown even more rapidly than the number of telephones, and now embraces about 85% of the total.

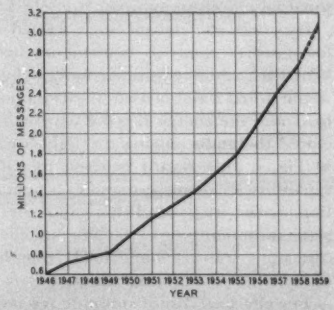


Fig. 2. Growth of transoceanic messages.

Even more striking has been the growth in the number of telephone conversations. In sizable areas in many parts of the world (for example, Canada; also the two newest additions to the United States, Alaska and Hawaii) the average for the whole population is about two telephone calls per person per day, and of course far more in the populated regions.

When it comes to intercontinental telephone calls, statistics are hard to come by. In default of other figures, suppose we look (Fig. 2) at transoceanic telephone messages terminating in the United States mainland. We used to refer to these as "overseas" messages, but now so many of them go underseas that we have had to find a new name. By almost any standard of comparison, the number of such transoceanic messages is small in the extreme. The rate of growth, however, is rather startling; now about 15% a year. Evidently transoceanic

E. I. Green is executive vice-president, Bell Telephone Laboratories, Inc, Murray Hill, N. J.

telephony is beginning to mushroom. But this is not the whole story, as we shall see.

The surge in overseas telephony is not at all surprising when we recall the history of transoceanic communication. Less than 100 years ago all communication across the ocean was by letter or personal messenger, using sailing ships. The first transatlantic telegraph cable was laid in 1858, but promptly failed. The next cable, in 1866, provided the first semblance of high-speed communication, for telegraphic material only. Not until 1927, when the first commercial radio telephone circuit was established between England and the United States, could the public talk to one another across the Atlantic. Even then the transmission performance of the radio circuits was subject to nature's vicissitudes and left much to be desired.

It was nearly three decades later when, after years of development and experimentation, the first repeatered submarine telephone cable system was placed in service across the Atlantic in 1956. Then for the first time there became available reasonably adequate numbers of transatlantic telephone circuits with transmission properties equaling or exceeding those of the best land line circuits. The effect upon usage was immediate and spectacular. In fact, traffic to England practically doubled in one year. At the same time, finding it so much easier to talk, people talked longer.

Thus, it became quite clear that transoceanic telephony had up to that time been limited, not by basic demand, but by available technology and facilities. So the rush was on. Other ocean cables with submerged repeaters followed in rapid succession, with still others now in the planning stage. Moreover, cable systems capable of yielding wider frequency bands began to enter the picture. So at last transoceanic communication began to realize its manifest destiny.

Thus far, the bulk of the service between continents has been for telephone and telegraph purposes. In addition, sporadic use has been made of facsimile, picture transmission, and sound broadcasting. More recently, there has been limited use of higher-speed data transmission. In addition, greatly slowed-down television has been employed for recording and subsequent broadcasting.

In the future, we may expect greatly increased demands for these types of services, and others as well. Governmental needs, already substantial, are growing apace and introduce special requirements stemming from the need for recording, coding, and visual information. Increased demands for data service, both on a switched and on a private-line basis, are clearly to be expected. Live television for entertainment, news, or other purposes is a distinct possibility. And some optimists even dream of television as an adjunct to the telephone.

TRANSOCEANIC CABLES

IT IS TEMPTING at this point to plunge immediately into the maelstrom of problems involved in true world-wide communication. However, let us instead approach these problems by way of various types of transmission media, systems and techniques that bear on the matter. The most logical starting point seems to be submarine cable systems. The extent of the ocean cable network now existing and projected is shown in Fig. 3.

Transoceanic cable systems of the type introduced in

Fig. 3. Present and proposed repeatered submarine cable routes.

1956, with submerged electron-tube repeaters, provide a bandwidth of about 144 kc. This, with one cable for each direction, affords 36 high-grade carrier circuits having a gross bandwidth of 4 kc per channel. But the cost of these circuits is so high, and the traffic demands so great, that two things are being done at the terminals to obtain greater efficiency of use. The first of these consists in the provision of new channelizing equipment employing 3-kc spacing per channel. This increases the number of talking circuits from 36 to 48. Through an ingenious frequency plan devised by British Post Office engineers, the speech impairment due to the closer spacing is considerably reduced.

The other forthcoming scheme at the cable terminals embodies an intricate and precise process for the vivisection of speech. This system is known as TASI, an acronym for Time Assignment Speech Interpolation. It takes advantage of the silent intervals present in each half of a two-way conversation. By the use of high-speed switching to interleave the voice spurts of different conversations, the carrying capacity of the cable for telephone conversations is doubled (Fig. 4). For a complete terminal this requires some 16,000 transistors, but it pays off handsomely. In general, this method is not applicable to services other than telephony.

Close on the heels of these terminal modifications will follow more efficient cable systems. Already, shallow water cables of British design carry 60 two-way 4-kc channels in a single cable between Newfoundland and Nova Scotia. A cable of this type, suitable for deep water laying, is to be placed between Newfoundland and Scotland in 1961. Another single cable design, suitable for 100 two-way 4-kc channels, is planned for service in 1963 (Fig. 5). And we may in due course expect to have cable systems, using either transistor or vacuum-tube repeaters, which will afford a substantially wider transmission band.

HIGH-FREQUENCY RADIO—IONOSPHERIC REFLECTION

DESPITE the rapid extension of transoceanic cables, with their great transmission advantage, high-frequency radio links using reflection from the ionosphere, in the range from about 5 to 30 mc, will continue to be a substantial part of the world communication network for years to come. The service performance of the high-frequency radio-telephone facilities is being improved by increasing use of single-sideband techniques, higher power output, and wide-spaced diversity reception. Unfortunately, congestion in the high-frequency radio spectrum is so great that in the immediate future it will be difficult, if not impossible, to find all the assignments needed for situations where other media are impracticable or inadequate.

OVER-THE-HORIZON RADIO—TROPOSPHERIC SCATTER

ONE OF THE interesting developments of recent years has been that of radio systems that make use of scattering in the troposphere to transmit wide frequency bands. Such systems, with relay stations up to 200 miles or more apart, are capable of use either for a number of telephone channels or for television. Systems of this type have been placed in Canada and Alaska, in the

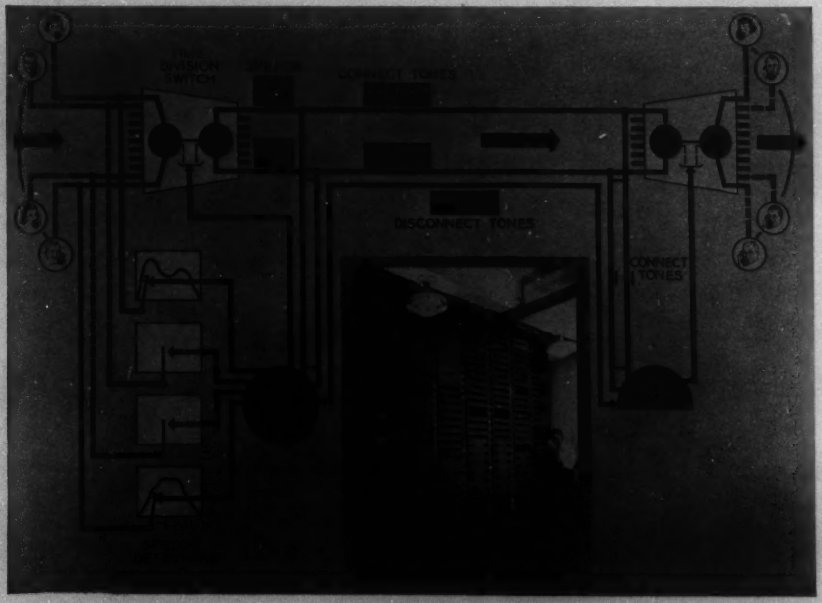


Fig. 4. TASI system.

Fig. 5. Submarine cable techniques. (*Top*) Painting of *H.M.S. Monarch* by Francis B. Savage. (*Bottom*) Rendering of the design of rigid repeater under development at Bell Telephone Laboratories. (*Left*) New type of armorless cable to be used in 1-mc system.

Caribbean area, and in Europe. These systems afford not only wider bands, but also more reliable transmission than the high-frequency ionospheric-reflection radio, and promise to have continuing use, especially for island communication. The most advantageous frequency range seems to lie between 500 and 2,000 mc.

SATELLITE COMMUNICATIONS

SPACE TECHNOLOGY offers another contribution to the transoceanic scene, namely, radio communication via satellites. The attractiveness of satellite communication systems lies in the possibility of obtaining wide transmission bands suitable either for handling television, if desired, or for larger volumes of narrower-band traffic, including military needs. There are two distinct possibilities, to wit, reflecting satellites and repeatered satellites. In the first of these (Fig. 6), a number of relatively low-altitude satellites (i. e., 2,000 to 3,000 miles above the earth, with a period of a few hours) would be placed in orbit (probably a polar one) to serve as passive reflectors. The total number of satellites needed might be from 15 to 30, depending on the desired continuity of service. Alternatively, clusters of small reflecting elements might be considered.

The other possibility, admittedly much more speculative and of longer range, is to place on the satellite an active relay station, consisting of a transmitter and receiver, with antennas and power supply. While active satellites might be at any distance from the earth, one attractive possibility is a satellite placed about 22,400 miles above the equator, with just the right orbit so that it would stay always above the same spot on earth.

Experiments on communication by means of reflecting satellites are already under way under the joint conduct of the U. S. National Aeronautics and Space Administration, the Jet Propulsion Laboratory of the California Institute of Technology, the Bell Telephone Laboratories, and others. The "sky mirrors" are 100-foot metallized plastic spheres (see cover). Ground transmitting and receiving sites are located near Goldstone Lake, Calif., and at Holmdel, N. J. The receivers include masers and traveling-wave tubes, together with an advanced method of demodulation employing FM with feedback. The antenna systems consist of paraboloids and a horn reflector (Fig. 7), aimed by extraordinarily precise tracking mechanisms.

While these experiments will shed some light on the feasibility of satellite communication systems, their success will depend on the most advanced art that research has to offer. There will be many complex technical problems still to be tackled, and the place of satellite systems in world communication remains to be seen. For one thing, the extremely high power required for the earth transmitters could result in widespread interference to other radio systems on the earth's surface. And conversely, high-power radar and other systems could produce serious interference in the ground-based satellite receivers. The preferred frequency region for satellite communication seems to be about 1,000 to 10,000 mc. Early consideration of international frequency allocations will be needed.

PULSE TRANSMISSION

APART from these techniques for effecting communication across the oceans, the art is overflowing with new techniques and devices which bid fair to revolutionize intracontinental communication and, in turn, react importantly on world communication.

New transmission systems employing digital techniques to replace analog counterparts offer great promise. In these, speech and other signals will be multiplexed by pulse methods, with channels interleaved in time instead of frequency. Indeed, pulses may well become the heartbeats of the new communication era.

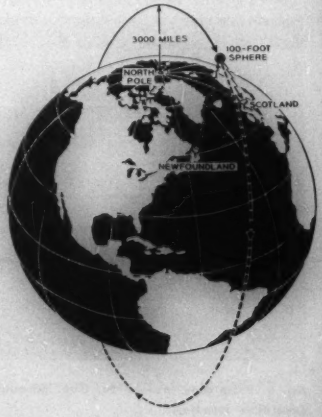


Fig. 6. Passive satellite for transatlantic communication.

Fig. 7. Experimental horn reflector antenna. (A similar reflector with 20-foot aperture is being constructed for satellite transmission experiments.)

Fig. 9. Television picture after transmission by 6-digit PCM.

In general, the most promising of pulse modulation methods is PCM (pulse code modulation), in which successive samples of the signal wave are transmitted by an extremely high-speed telegraph code (Figs. 8 and 9). The pulse code method provides, at the expense of bandwidth, low vulnerability to interference. The pulse signals can be regenerated at each repeater, so that accumulative distortion can be kept small. Thus, the time-honored problems of noise and crosstalk may be exchanged for new ones centering in synchronization and delay correction. Field experiments are already under way in the United States on a PCM carrier system for short trunks in metropolitan areas.

WAVEGUIDE SYSTEM

One likely application of PCM will be in a waveguide transmission system being developed in the United States to provide greatly increased information-carrying capacity on major overland communication routes when needed in future. The transmission medium will be a hollow dielectric-lined copper pipe or a helix, about 2 inches in diameter, acting as a guide for radio waves traveling inside. The system will employ the circular electric transmission mode (TE_{01}), which decreases attenuation with increasing frequency.

The frequency band transmitted inside the waveguide may extend from 35 to 75 kilomegacycles, i. e., a gross band nearly four times as wide as the entire band now used for radio communication. The same band can be used, for either direction, inside adjacent pipes. The waveguide, therefore, will yield a vast frequency spectrum not vulnerable to fading, atmospheric effects, interference, or other troubles that beset the radio, and not subject to public demands and consequent governmental restrictions. Within this frequency band, a large number of broadband channels will provide a handling capacity for perhaps as many as 200,000 voice circuits or 200 television pictures.

Fig. 8. Pulse code modulation. (Top) Schematic diagram. (Bottom) Regenerative repeater.

ELECTRONIC SWITCHING

Switching is just beginning to feel the full impact of the new electronic art. All of the automatic switching systems up to now have been built around the electromagnetic relay and other electromechanical devices. Such devices are, in modern terms, quite slow; they require some thousandths of a second to operate. In contrast, electronic devices will perform switching or complex logical operations in a few microseconds.

New switching systems under development will profit from this high speed through centralizing of functions and time-sharing of the computer and control apparatus. In contrast to an electromechanical switching office, where all instructions had to be wired into the equipment, the electronic office will afford a high degree of versatility through programs stored in memory. Such features as simplified codes for reaching frequently called telephones wherever located, automatic subsequent completion of "line busy" calls, automatic transfer of incoming calls to any specified telephone, automatic centralized answering service, and the like should become commonplace. These electronic switching systems should in due course provide faster interconnection and greater flexibility for handling complex translations and other difficult switching problems.

(To be concluded in the July *Electrical Engineering*.)

Recording Instrumentation for Steam Turbines

H. A. HARRIMAN
ASSOCIATE MEMBER AIEE

D. M. LONGENECKER
MEMBER AIEE

INSTRUMENTATION for recording turbine speed, eccentricity, expansion, and vibration is now widely used on large steam turbines, particularly those over 80,000 kw. Most previous instrument systems for these measurements utilized four individual ink-type recorders; hence, one objective in developing a new instrument system was to use fewer recorders, reducing the panel space required. In addition, a high degree of reliability, long life, and good accessibility for inspection and servicing were major objectives.

Fig. 1 shows the panel-mounted equipment of a typical instrument system. Two wide-chart recorders are used, the one on the left being a duplex direct-acting ink-type recorder having two separate recording mechanisms, each with its own pen. On the left half of the chart, turbine speed or valve position is recorded by the first pen. While the turbine is being started, a record is made of the speed, but after the generator is connected to the line, the equipment is automatically switched to record valve position. On the right half of the duplex recorder chart, shaft eccentricity is recorded. The eccentricity measuring equipment provides two modes of operation, the first used with the turbine on turning gear, while the second is automatically connected when the turbine is running at speeds from 550 rpm to synchronous speed.

The recorder on the right is of the automatic null-balancing d-c potentiometric type, equipped with multipoint printing and capable of recording up to 16 channels of information at the rate of 1 channel every 5 seconds. To provide good legibility of records when recording a large number of channels of information, the chart is divided into three sections. In the left third of the chart, either one or two channels of shell expansion and one or two channels of differential expansion are recorded, depending on the turbine. The middle chart section is used to record up to six vibration channels, and the right chart section is used to record up to six additional vibration channels.

By duplicating portions of the equipment shown in Fig. 1, cross-compound turbines can be instrumented, using three of four recorders. Similarly, portions of the equipment can be omitted in instrumenting small steam turbines, gas turbines, compressors, or fans.

Immediately below the recorders in Fig. 1 are the small draw-out units ("power units") containing the measuring circuitry used with the recorders. A motor-generator set (not shown) is used in place of an electronic oscillator, to provide the 415-cps carrier voltage for the eccentricity recording equipment.

Detectors used on the turbine include a conventional tachometer generator for speed and a potentiometer for valve position. For eccentricity, a variable-impedance, high-frequency-excited detector is mounted 1/16 inch away from a steel wheel located on an extension of the turbine shaft. The shell expansion detector consists of two core-and-coil units facing an armature, which is moved as the turbine shell expands.

Courtesy Houston Lighting and Power Company

Fig. 1. Panel-mounted portion of a typical instrument system. (The control switches, indicator lights, and pushbuttons are not part of the instrumentation.)

Two detectors are used in the measurement of differential expansion, one located in front of and one to the rear of a wheel which is part of the turbine rotor. By enclosing the detector core and coils in a stainless steel case filled with an epoxide resin, a new moisture-proof differential expansion detector has been developed for use within the low-pressure hood.

Since the bearing pedestals of large turbines are rigid and massive compared with the rotor, a new shaft vibration detector of the probe type has been developed. The probe is installed into an entry-hole provided in the turbine bearing, as contrasted with the earlier practice of mounting the detector on the bearing housing. Included in the probe is a spring-loaded pushrod fitted with a bronze rider-tip operating in contact with the turbine shaft, with a velocity-type vibration detector-head at the outer end of the pushrod. Life tests performed on bronze rider-tips at 13-pounds spring pressure and a rubbing speed of 280 feet per second have shown a wear less than 0.0003 inch per year.

In the event of excessive vibration, the new instrument system gives an alarm in 1.5 minutes or less. The equipment requires only 6 square feet of panel space and uses only 7 vacuum tubes, providing greatly improved reliability over the more complex 22-tube instrument system previously used.

Digest of paper 59-1109, "New Instrument Systems for Recording Turbine Speed, Eccentricity, Expansion, and Vibration," recommended by the AIEE Power Generation Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill., Oct. 11-16, 1959. Published in AIEE *Power Apparatus and Systems*, Feb. 1960, pp. 1626-34.

H. A. Harriman and D. M. Longenecker are with the General Electric Co., West Lynn, Mass.

Field Treatment in Electric Shock Cases—II

W. B. KOUWENHOVEN
FELLOW AIEE

G. G. KNICKERBOCKER
ASSOCIATE MEMBER AIEE

W. R. MILNOR

J. R. JUDE

Additional data on the field treatment of men who have been rendered unconscious by electric shock.[1]

IT IS WELL KNOWN[1] that an alternating current from 0.1 to several amperes flowing from the hands to the feet may upset the rhythm of the heart and throw it into ventricular fibrillation, but that it does not paralyze the respiration. Larger current values will hold the heart in systole while the current is flowing, and when the circuit is broken the heart usually resumes normal beating. These larger currents, however, often temporarily paralyze the nerves leading from the brain to the lungs, and thus stop the respiration. It has also been determined that some high-voltage electric shock cases, producing severe burns, do not affect either the heart or the lungs. The reasons for this anomalous variation is not understood.

In ventricular fibrillation the pulse disappears and the heart stops pumping blood. The victim usually gasps for breath for a brief time before the lack of oxygen stops respiratory center activity. Therefore, in both ventricular fibrillation and paralysis of the respiration, the victim usually will have ceased to breathe by the time help reaches him. The only means today that the rescuer has of saving the victim is to apply manual artificial respiration.

TREATMENT OF RESPIRATORY FAILURE

WHEN A MAN IS RENDERED UNCONSCIOUS by an electric shock and is not breathing, manual artificial respiration should be started *at once*. This is of prime importance as the human brain will suffer irreparable damage if it is completely deprived of oxygenated blood for 3 minutes. Artificial respiration should be continued until either the victim revives or rigor mortis sets in.

There are a number of manual artificial respiration methods. During the 3-year period, 1956 through 1958, the methods used most commonly by the electric utility companies were the Back-Pressure Arm Lift and the Pole Top. Table I presents a compilation of the experiences reported to the Edison Electric Institute (EEI) by the utilities using these two methods. The table includes only cases where artificial respiration was started within 3 minutes after the shock.

The Back-Pressure Arm-Lift method has been criticized because of the difficulty of maintaining a patent airway. The Mouth- to-Mouth[2] method of insufflation, which was practiced by the Prophet Elisha[3] almost 3,000 years ago, is without question most effective. It must be remembered, however, that with a free airway any one of the manual methods will provide sufficient ventilation to give nature the opportunity to overcome the temporary paralysis and re-establish normal breathing. It should also be kept in mind, that all failures to resuscitate listed in Table I are not due to inadequate ventilation. Some of these men, perhaps as many as 50%, died of ventricular fibrillation.

Table I. Artificial Resuscitation Attempts Started Within the First 3 Minutes After the Contact

	Back-Pressure Arm-Lift			Pole Top		
Voltage Range	Cases	Saved	Failures	Cases	Saved	Failures
110–750	5	0	5	3	0	3
1,300–2,700	30	5	25	33	17	16
3,500–6,000	8	3	5	8	4	4
6,000–8,500	36	13	23	33	13	20
10,000–20,000	5	2	3	3	3	0
20,000 plus	16	7	9	2	1	1
Totals	100	30	70	82	38	44

TREATMENT OF VENTRICULAR FIBRILLATION

THE ONLY RELIABLE and effective method of stopping ventricular fibrillation is to send sufficient electric current through the heart to contract it and bring its twitching fibers to rest. The closed-chest hospital type of defibrillator[4] that was developed is designed to do this. An alternating current of 5 amperes, at 440 volts, for ¼ second, is sent through the victim's chest between electrodes placed on the suprasternal notch and about one inch below the left nipple (Fig. 1).

The defibrillating equipment (Fig. 2) is mounted on a movable table 16 by 20 inches in size and 30 inches high. On the lower shelf is a 3-kva 120- to 480-volt low-impedance transformer. In front of the table, on the floor, may be seen the explosion-proof foot switch. On top of the table, at the left, is a double-pole main switch for controlling the 120-volt supply circuit; on top, at the right, is a clock-driven timer, which controls the duration of the shock, and which requires no warmup time. On the center of the table top is mounted a pilot lamp and a selector switch for selecting either 480 volts for adults, or 240 volts for small children. The elec-

Essentially full text of paper 60-171 plus an appendix, recommended by the AIEE Safety Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Winter General Meeting, New York, N. Y., Jan. 31–Feb. 5, 1960. Scheduled for publication in AIEE *Power Apparatus and Systems*, 1960.

W. B. Kouwenhoven, G. G. Knickerbocker, W. R. Milnor, and J. R. Jude are with the Johns Hopkins University, Baltimore, Md.

The authors wish to thank the National Heart Institute, U. S. Public Health Service, for a grant in support of this work, and the Edison Electric Institute for its assistance.

trodes, which are 9 square inches in area, are held by clips on the front of the table. The main contactor and the switches are enclosed in explosion-proof boxes.

When an emergency arises, the defibrillator is wheeled into place, the electrodes are taken from their holders, and electrode paste applied. The foot switch is placed on the floor convenient to the operator, who takes the electrodes and places them on the patient's chest in the position illustrated in Fig. 1. Then, pressing firmly on the electrodes, the operator steps on the foot switch, sending the defibrillating shock through the heart.

At the Hopkins Hospital there are four of these defibrillators, three located at strategic positions and one available for use throughout the Hospital. The first defibrillator was installed in March of 1957. The equipment has never failed to arrest a ventricular fibrillating heart although in some cases a second shock, given some 15 or 20 seconds later, has been necessary. Closed chest defibrillators are manufactured by several firms and are now in use in a number of hospitals. This type of defibrillator has been applied a considerable number of times and, to the best of our knowledge, has produced no trauma, nor has it injured a normally beating human heart.

Fig. 3 presents one of those extremely rare instances where ventricular fibrillation occurs during cardiac catherization. The cardiogram shows the patient's normal heart record, the onset of fibrillation, its characteristic pattern, and the recovery of normal heart action after defibrillation. The defibrillating shock was given some 80 seconds after the onset of the emergency. The patient's chest was not opened and he went home the next day.

A PORTABLE DEFIBRILLATOR

THE MINE SAFETY APPLIANCES COMPANY is co-operating with us in the development of a portable cardiac defibrillator for possible use in the field. The problem of reducing the size and weight involves many factors which are being solved gradually. Any closed chest defibrillator must be so designed that the electric shock, which it sends through the chest, will not harm a normal heart. This factor alone involves innumerable tests.

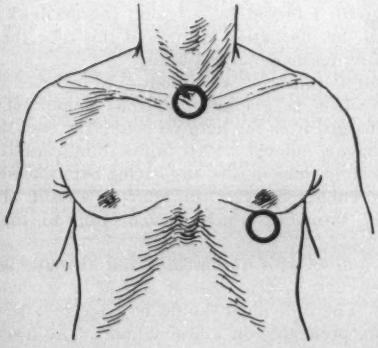


Fig. 1. Position of electrodes on the surface of the chest in defibrillation.

TIME LIMITATION

ANOXIA, or the lack of oxygen nutrient to living tissues, places a serious limitation on the length of time that may lapse between the onset of fibrillation and its termination.

In the absence of external aids to circulation of blood, the heart should be defibrillated within 2 minutes if the heart is to resume spontaneous normal activity, and if organs of the body, most particularly the brain, are not to be irreversibly damaged. This requires that the defibrillator be immediately available and ready for use when the emergency occurs.

In the hospital, the time limitation may be extended by opening the chest and massaging (squeezing) the heart with the hand 40 to 60 times per minute. This technique, if properly performed, will produce a palpable pulse and sufficient circulation to keep the brain alive and maintain the tone of the heart. Direct massage of the heart may be continued for an hour or more; thus, ample time is available for bringing a defibrillator to the scene. The open-chest technique, however, involves a major surgical procedure, and is not suitable for use in the field.

EXPERIMENTAL CLOSED-CHEST HEART MASSAGE

IN AN EFFORT to prolong the time that one has to get the defibrillating equipment organized and still maintain hope of saving the shock victim, we have been carrying on experiments in maintaining adequate circulation during fibrillation. We have found in the experimental dog, with arrested heart, that it is possible to provide circulation of the blood by forcefully compressing the animal's chest. The technique with the

Fig. 2. A-C closed-chest defibrillator.

Table II. Closed-Chest Heart Massage in the Dog

Minutes in Fibrillation	Tests	Resuscitated	Surviving
2	9	8	8
3	5	5	5
4	6	6	5
5	7	6	5
6	3	3	3
8	2	1	1
10	5	5	4
15	2	1	1

animal in supine position is to place both hands, one on top of the other, on the animal's mid-chest and to press downward toward the spine about 100 times per minute. This action squeezes the heart, which is relatively fixed in position between these two bony structures, and expels blood from its chambers into the blood vessels. Experimental measurements have shown sustained elevation of average blood pressure of 25 to 40% of normal and a flow of blood to the head of 30% of normal.

Anesthetized animals were used in the study. Tubes were inserted in their tracheas, insuring open air ways, and their hearts were fibrillated with 110-volt shocks. After one minute had elapsed, simulating the time needed to get to the shock victim, the breathing had stopped and the reflexes disappeared. Then compression of the chest, external heart massage, was begun, without the application of additional artificial respiration. It was noted that after about one minute of massage, the breathing was resumed spontaneously and the reflexes reappeared, as oxygenated blood was supplied to the brain and heart. Fibrillatory electrocardiograph activity, which normally diminishes in prolonged fibrillation, was sustained at a vigorous rate. The animals were defibrillated with the first applications of the defibrillator. Restoration of heart activity and return of spontaneous blood pressure occurred regularly after the defibrillating shock. In a majority of these cases the animals were returned to their cages and recovered with little or no sign of permanent damage to heart, brain, or other organs. Table II summarizes the results of these tests.

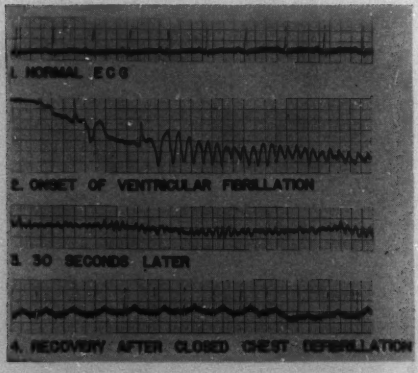


Fig. 3. Electrocardiogram of a ventricular fibrillation instance in a human being.

CLOSED-CHEST HEART MASSAGE IN MAN

At present the method is being applied successfully to hospital patients who suffer cardiac arrest.

If this technique should continue to be a safe and effective method of providing circulation, as it gives every indication of doing, it will: (1) reduce the need for opening the chest in cardiovascular emergencies, and (2) provide the extra minutes that are needed to get a defibrillator to those victims of electrical accidents whose hearts are fibrillating.

The technique of closed-chest heart massage is simple to apply. In fact, it is not as complicated as the back-pressure arm-lift method of artificial respiration. We do not suggest that it be used to replace artificial respiration; we feel that better results can be attained using both artificial respiration and closed-chest heart massage simultaneously.

Appendix

Early in January 1960, a 45-year old man was brought into the Johns Hopkins Hospital suffering from excruciating chest pains radiating down both arms. After a preliminary examination he was asked to undress and get into bed. While the man was undressing, the house officer heard a fall and rushed into the room. The patient was on the floor, unconscious, not breathing, and having no pulse. With the patient on the floor, the doctor immediately started closed-chest cardiac massage, and sent for an electrocardiograph and an anesthetist.

An electrocardiogram showed that the man's heart was in ventricular fibrillation, and a hospital closed-chest a-c defibrillator was sent for. The anesthetist began to give artificial respiration 10 minutes after the doctor had started the external massage.

The massage and artificial respiration were continued until a defibrillator arrived about 15 minutes later. Application of the closed-chest a-c defibrillator was made after about 25 minutes of continuous external massage. The shock halted the fibrillation for a short period of time, but the heart then reverted to ventricular fibrillation. Three more minutes of external massage were given, followed by a second countershock. This stopped the fibrillation again, and this time the heart gradually resumed natural beats.

The patient had amnesia, which continued for several hours, after which he gradually returned to normal. He was discharged from the hospital before the end of the month, having suffered neither injury to his central nervous system nor broken ribs, and having been spared thoracotomy. He has, however, an infarct as a result of the coronary thrombus which brought him to the hospital.

When an individual is unconscious, and his pulse is absent, closed-chest cardiac massage should be started *immediately*. The individual should be lying in a supine position, preferably on a firm support. The heel

of the lower of the operator's two hands should be placed on the breast bone close to its lower end. On a child one hand may be used. If there are two individuals present, the second one should give artificial respiration, either by mouth-to-mouth or mouth-to-nose, at the usual rate.

Our experience at the Johns Hopkins Hospital has proved that closed-chest cardiac massage will provide adequate circulation to maintain the tone of the heart and prevent injury to the brain for periods as long as ½ hour. This should provide ample time to summon assistance and equipment.

Closed-chest cardiac massage now has been applied to 34 patients whose hearts developed cardiac arrest. All of these except 5 were resuscitated, and 13 returned alive to their homes.

REFERENCES

1. Field Treatment of Electric Shock Cases–I, W. B. Kouwenhoven, W. R. Milnor. AIEE *Transactions*, pt. III *(Power Apparatus and Systems)*, vol. 76, April 1957, pp. 82-84.

2. Comparison of Mouth-to-Mouth and Mouth-to-Airway with Chest Pressure Arm Lift Artificial Respiration, P. Safar. *New England Journal of Medicine*, Boston, Mass., vol. 258, 1958, p. 671.

3. The Holy Bible, II Kings 4, v. 32.

4. Closed Chest Defibrillation of the Heart, W. B. Kouwenhoven, W. R. Milnor, G. G. Knickerbocker, W. R. Chesnut. *Surgery*, St. Louis, Mo., vol. 42, 1957, p. 550.

Moon-Reflection Studies with Bistatic Radar at 3,000 Mc

A. W. STRAITON C. W. TOLBERT

Measurements have been made to demonstrate the feasibility of receiving moon-bounce signals approximately one fourth of the distance around the earth. This study will give information about the moon's motion and surface, as well as the Faraday rotation in the ionosphere.

MEASUREMENTS have been made of moon-reflected radar signals transmitted by the Royal Radar Establishment from Malvern, England, and received by the Electrical Engineering Research Laboratory of The University of Texas at Austin, Texas. These supplement monostatic radar measurements made by a number of organizations and a few bistatic measurements which have been noted in news articles and mentioned at technical symposia. Reports have been made of monostatic measurements in the very-high-frequency (vhf) band by Trexler and Evans and in the 3,000-mc region by Yaplee and Hughes.[1-4]

The measurements reported in this article were made to demonstrate the feasibility of receiving moon-bounce signals approximately one fourth of the distance around the earth and to obtain information on the character of the signals received over this path. The signal study should shed light on the surface of the moon, distance to the moon, the Faraday rotation in the ionosphere, and the motion of the moon.

It is obvious that signal detection is made easier by an increase in transmitted power and in the gain of the transmitting and of the receiving antennas. For the higher frequencies, the gain for a given size antenna is increased but so also is the cost of construction.

BANDWIDTH

THE SIGNAL-TO-NOISE RATIO may be increased by decreasing the bandwidth. This bandwidth must, however, be wide enough to accept any changes in frequency due to Doppler effects associated with the earth's rotation, the moon's libration, and changes in distance between the earth and the moon. The bandwidth must also be wide enough to avoid pulse distortion. For this latter reason, it is possible to make measurements with comparably low-power continuous wave operation, while higher-peak power is needed for pulse operation.

SCATTERING CROSS SECTION OF THE MOON

THE ONLY UNCERTAIN FACTOR in the radar equation, as applied to the moon returns, is the back-scattering cross section of the moon. This reflection is dependent on the smoothness of the moon surface relative to the wavelength used. For wavelengths of several meters, the moon's surface has been described by Siegel as quasi-smooth, implying that large areas of the moon are relatively smooth for this wavelength.[5] It would be expected, however, that for centimeter wavelengths, the moon's surface would appear rougher and have more areas which would serve as effective reflecting regions.

Full text of paper 60-518, presented at the AIEE Southwest District Meeting, Houston, Texas, April 4-6, 1960. Recommended for publication by the AIEE Radio Communication Systems Committee. Scheduled for publication in AIEE *Communication and Electronics*, 1960.

A. W. Straiton and C. W. Tolbert are with The University of Texas, Austin, Texas.

This work was possible only because of the excellent co-operation of the Radio Astronomy Group at the Royal Radar Establishment in England, who provided the essential transmission as well as many valuable suggestions concerning the reception technique.

The work conducted by the Electrical Engineering Research Laboratory of The University of Texas and described in this article was sponsored by the Wright Air Development Center under Contract AF 33(616)-6257.

In addition to the roughness, the reflections from the moon will be influenced by the nature of the surface. A thick layer of low-density dust might serve to reflect only a small amount of energy from the surface, with additional reflections taking place from a solid layer beneath the dust.

POLARIZATION EFFECT

For a linearly polarized transmitting antenna, the polarization at another location may be determined for two earth stations in the Northern Hemisphere north of the sublunar geographical position (GP), the first location observing after lunar transit and the second location observing before transit, by the following equation:

$$p = \tan^{-1}\left[\cot\frac{A}{2}\left(\frac{\cos\frac{L_x-L_m}{2}}{\sin\frac{L_x+L_m}{2}}\right)\right]-\tan^{-1}\left[\cot\frac{A}{2}\left(\frac{\sin\frac{L_x-L_m}{2}}{\cos\frac{L_x+L_m}{2}}\right)\right]$$
$$+\tan^{-1}\left[\cot\frac{B}{2}\left(\frac{\cos\frac{L_y-L_m}{2}}{\sin\frac{L_y+L_m}{2}}\right)\right]-\tan^{-1}\left[\cot\frac{B}{2}\left(\frac{\sin\frac{L_y-L_m}{2}}{\cos\frac{L_y+L_m}{2}}\right)\right] \quad (1)$$

where

p = polarization
L_m = sublunar latitude
L_x = latitude of the first station
A = difference in longitude between the lunar ground position and the first station
L_y = latitude of the second station
B = difference in longitude between the lunar ground position and the second station

If the linearly polarized receiving antenna is rotated with respect to the polarization of the incoming wave, the signal strength will be reduced by the cosine of the angle between the polarization of the antenna and that of the incoming wave. Thus, a change in signal level caused by polarization effects will be encountered during a measurement period as the sublunar latitude and longitude vary as a function of time.

FARADAY ROTATION

The polarization of the radio wave going through the ionosphere will be rotated through an angle α due to the movement of the charges by the wave in the earth's magnetic field. The direction of rotation will be additive for the return trip. The amount of this rotation is given for radar frequencies greater than 100 mc by

$$\alpha = \frac{e^3}{2\pi m^2 c^2 f^2}\int_l^0 N(s)\,H(s)\,ds \quad (2)$$

where e and m are the charge and mass of the electron, c is the velocity of light and f is the radar frequency. $N(s)$ and $H(s)$ are the electron density and magnetic field, respectively, along the transmission path l over which the integral is taken.

It is noted that this effect varies inversely as the square of the frequency. Extrapolating the results of vhf measurements indicates that this effect would be very small at 3,000 mc.

TRANSMITTED DATA

The transmitting station was located at Malvern, England, at a latitude of 52.1°N and a longitude of 2.3°W. The transmitting antenna was a 45-foot parabola which transmitted 5-microsecond pulses at a repetition rate of 250 per second. The transmitted frequency was very nearly 3,000 mc, with a power of 2 megawatts. By prearranged agreement, the repetition rate was maintained at 250 per second with a deviation of less than one part in 10^8. Previous monostatic measurements at Malvern had shown a reflected signal strength at the receiver of 10^{-13} watts.

RECEIVER DATA

The receiver for the studies was located at the Balcones Research Center of The University of Texas, at a latitude of 30.4°N and a longitude of 97.7°W. This is equivalent to an hour-angle separation of 6 hours and 22 minutes from Malvern and a great circle distance of 4,780 statute miles.

The receiving system, shown in block diagram in Fig. 1, was designed and assembled primarily to detect and identify the moon-reflected signal as transmitted from Malvern. The antenna and the r-f amplifier are the "heart" of the system, the other components being designed to be complementary and to display the received signal. The skin of the 28-foot antenna, a parabola formed by eight sections of Fiberglas-reinforced copper foil, was supplied by Wright Air Development Center. A framework of aluminum and steel trusses was fabricated that allowed the skin to be attached to an *F/SCR-268* radar mount. The resulting altazimuth mount was optically pointed with a telescope gunsight. Tracking of the moon was manual and was facilitated through the use of a television camera and receiver aligned with the gunsight. The parabolic reflector was horn-illuminated with a 10-db taper and the waveguide feed from the horn terminated at the r-f amplifier. The resulting gain and beamwidth were calculated to be 46 db and 0.8 degree, respectively. A Hughes Products *PAS-2* backward-wave amplifier (bwa) was attached to the antenna mount as shown in Fig. 2, and the coaxial cables to its input were utilized to form the vertical rotary joint. The output from the bwa, operated with a gain of 20 db and a noise figure of 5 db, was waveguide-coupled to a balanced mixer and thence to an i-f amplifier with a bandwidth of 400 kc. The local oscillator, a *6BL6* klystron, was used to heterodyne to the i-f frequency of 44.5 mc, with no frequency stabilization being employed other than that inherent in the system.

The output of the second detector, after passing through a video amplifier, was applied to two cathode-ray oscilloscopes, one with a P_{11} screen for photographic purposes and the other with a P_2 screen for eye observations. Synchronizing pulses with a repetition rate of 250 ± 10^{-6} per second were derived from a Hewlett-

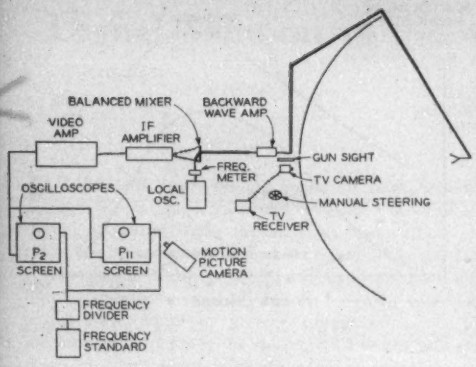


Fig. 1. Receiver block diagram.

Packard Company frequency standard. Interval markers at 20 seconds were also derived for timing purposes. Provision was made for recording with a 16-mm motion picture camera, a Type A signal display, and a display similar to that used at Malvern, where the signal is applied to the z axis of an oscilloscope whose x and y co-ordinates are 80 seconds and 1,000 microseconds. The 1,000-microsecond sweep was synchronized with the pulse repetition rate.

The beamwidth and the pointing of the antenna were measured by means of a signal generator on top of a 270-foot tower at a distance of 2,500 feet. Observations also were made using the sun as a signal source. Prior to the measurements, the Royal Radar Establishment provided the transmitter frequency within ± 0.1 mc and the periods when the transmitter would be operated.

MEASUREMENTS

THE FIRST ATTEMPT to receive the signal, made on August 22, 1959, with vertical antenna polarization, was unsuccessful. Failure was due, in part, to the antenna polarization and to a difference in indicated transmitter frequency as measured at Malvern and at Austin. The second attempt was made on the following night with horizontal polarization. Approximately 2 hours after moonrise, the signal was tuned in. The adjustable parameters of the receiver were optimized and eye observations and photographs of the intensity modulation display were made. Stratus clouds prevented optical sighting of the moon on the following night, thereby prohibiting the pointing of the antenna. The fourth night of the prescheduled measurements was canceled by mutual agreement, primarily due to the poor weather conditions at Austin but also to allow antenna repairs to be made at Malvern.

A second set of measurements was scheduled for the period between September 21 and September 24. Because of the narrow latitude permitted in adjusting the parameters of the intensity modulation scheme with the low signal-to-noise ratio experienced during the previous measurements, motion picture recordings of the Type A presentation were made during this period. No difficulty was experienced in tuning in the signal during this period. On September 21, photographic recordings and eye observations of the signal were made for approximately 5 hours with 45-degree counterclockwise antenna polarization. Low stratus clouds prevented antenna pointing on September 22. Measurement were made for approximately 5 hours with horizontal polarization on September 23. The measurements scheduled on September 24 with vertical polarization could not be made because of cloud cover.

Shown in Fig. 3 are typical recordings of Type A displays of the moon-reflected signal at four different sweep speeds. On each frame of the film there were superimposed approximately 10 sweeps. The observed upper 6 db of the reflected signal has cumulative characteristics which can best be described as being similar to noise. Signal returns were distributed over a time interval of 350 microseconds after the earliest return. This corresponds to receiving signals from a number of areas on the moon's surface with the maximum signal coming from a depth of approximately 7.5 kilometers back of the nearest point on the moon. The greatest time delay corresponded to a depth of approximately 50 kilometers, which would occur at about one third of the distance from the center to the edge of the optical disk. The interval time during which the upper 6 db of a single discrete return could be observed averaged approximately one-quarter second. The mean distribution of signal amplitudes vs. time are shown in Fig. 4. The spectra which were enhanced by frequency-modulating the sweep repetition rate about 20 microseconds at 2 cycles per second were primarily determined by eye

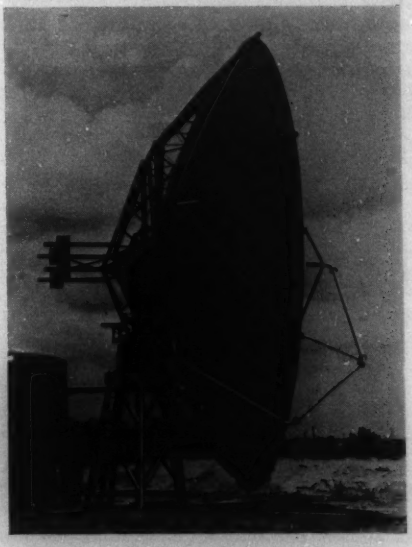


Fig. 2. Receiving system.

observations of the P_2 screen. A more extended period of returns was observed with 45-degree counterclockwise polarization than with horizontal polarization. Also shown in Fig. 4 are the relative amplitudes of the signal strengths observed with horizontal and 45-degree counterclockwise antenna polarizations as the moon traversed between the zenith at the two terminals. The values of a signal attenuation caused by the rotation of the polarization of the reflected signal as calculated by equation 1 are also shown in the figure. The curves of the observed and the calculated signal strength were adjusted to fit at the point of maximum signal strength.

SUMMARY

THE MOON-REFLECTED signal as transmitted from Malvern, England, was easily received in Austin, Texas, with a 28-foot antenna and a receiver with a noise figure of approximately 6 db. The upper 6 db of the spectra of the reflected signals were made up of a large number of pulses of varying amplitudes and positions along a time base of approximately 350 microseconds. The maximum returns occurred approximately 50 microseconds after the first return. The average polarization of the reflected signal was essentially linear and has a value which correlates reasonably well with that calculated for a plane reflecting surface. The complex nature of the reflection prevented any conclusions other than those relating to the effective reflecting areas of the moon and to the average polarization.

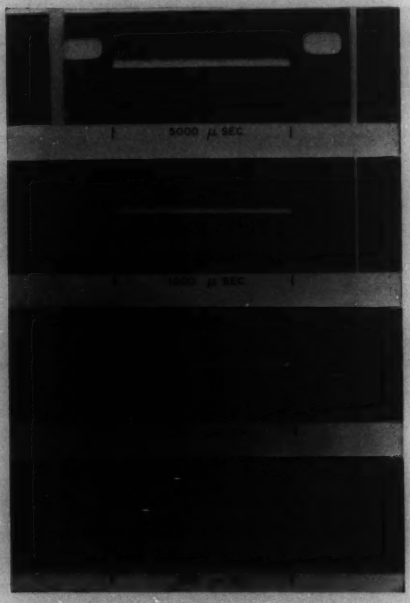


Fig. 3. Type A presentation of moon-reflected signals.

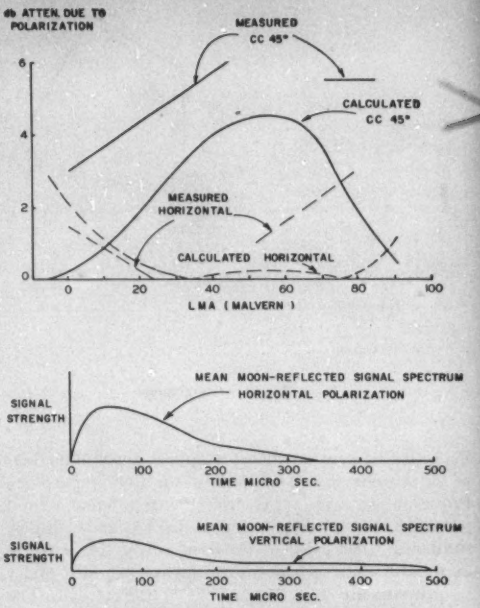


Fig. 4. Spectra and polarization of reflected signals.

Appendix

The signal-to-noise ratio for echoes from the moon is given by

$$\frac{P_s}{P_n} = \frac{P_T A_R G_T \sigma}{16\pi^2 R_T^2 R_R^2 F K T b}$$

where

P_s = signal power at receiver
P_n = noise power
P_T = transmitter power
A_R = effective area of receiving antenna
G_T = gain of transmitting antenna
σ = scattering cross section of target
F = receiver noise
K = Boltzmann's constant
T = receiver ambient temperature
b = receiver bandwidth
R_T = distance from transmitter to moon reflecting region
R_R = distance from receiver to moon reflecting region

REFERENCES

1. Lunar Radio Echoes, J. H. Trexler, *Proceedings*, Institute of Radio Engineers, New York, N. Y., vol. 46, 1958, p. 286.

2. The Scattering of Radio Waves by the Moon, J. V. Evans, *Proceedings*, Physical Society, London, England, vol. 70, pt. B, 1957, p. 1105.

3. Radio Echoes from the Moon at a Wavelength of 10 Cm, B. S. Yaplee, R. A. Burton, K. J. Craig, N. C. Roman, *Proceedings*, Institute of Radio Engineers, vol. 46, 1958, p. 293.

4. Radar Moon Reflection Studies at 3000 Mcs, V. A. Hughes, Paris Symposium on Radio Astronomy, URSI, Stanford University Press, Stanford University, Calif., 1959.

5. Studies in Radar Cross Section; chap. 28: The Physics of Radio Communications Via the Moon, M. L. Barash, H. Bryk, B. A. Harrison, T. B. A. Senior, K. M. Siegel, H. Weil, *Technical Report*, Contract AF 30(602)-1725, Engineering Research Institute, The University of Michigan, Ann Arbor, Mich.

Digital Solution of Network Short-Circuit Currents

A. L. TOALSTON
ASSOCIATE MEMBER AIEE

PHASE and line-to-ground faults for large networks can be economically determined on a medium-size digital computer using the methods discussed. A program has been written and tested on a 2,000-word IBM (International Business Machines Corp.) *650* computer. Similar programs could be written for other computers which have equal or greater storage capacity. The method presented uses the short-circuit tensor and symmetrical components with the same assumptions and basic data as is used for network analyzer studies. Negative impedances and mutual impedances are properly represented.

The assumptions normally made for the solution of short-circuit currents permit any network to be reduced to an equivalent star, with each ray having a self-impedance and a mutual impedance to every other ray. The short-circuit tensor is simply an array of the impedances for the equivalent network.

The digital program consists of three basic phases: (1) calculation of a network tree, (2) calculation of a short-circuit tensor, and (3) calculation of fault and line currents. The network tree and short-circuit tensor need be calculated only once for each of the positive and zero sequences of a given network. The short-circuit tensors can be modified easily when going from minimum to maximum conditions or for future network changes. The cards on which the short-circuit tensors are represented are, thus, easily corrected as the network changes. These cards may be kept as a permanent record of the network equivalents.

The short-circuit tensor serves as the basic data for the fault calculations. After it is derived, faults require an average of about 5 seconds each. About 200 line currents or mva values can be calculated and punched out per minute. Only those line currents or mva that are desired are calculated. The output is in mva for 3-phase faults, and amperes for line-to-ground faults. No manual calculations are required to change from per-unit values or to correct for different nominal voltages. The output is suitable for listing in report form including alphabetic line names and description of faults.

Voltages are easily found at each node of a network from the short-circuit tensor. The voltages are then used to determine line currents for the fault condition. Any line current is equal to the difference of the voltages at the nodes to which the line is connected, divided by the impedance of the line unless the line is mutually coupled to one or more other lines in the network. If there is mutual coupling, the simple E/Z relationship does not hold, but the mutual impedance can be separated from the self-impedance of the line. The insertion of a fictitious node in each line of the network which is mutually coupled with one or more other lines makes it possible to solve directly for the current in the line. The fictitious node also makes it possible to open the line mathematically without disturbing the lines to which it is coupled.

Storage limitations of the 2,000-word IBM *650* computer restrict the subject program to 35 nodes or less for a single pass on the computer. Fortunately, fault studies are such that only those line currents in the portion of the network near the faulted bus are usually required. Thus, large networks can be solved in sections, and only a small overlap of the sections is required.

The size of the short-circuit tensor is determined by the number of nodes. Thus, there is considerable advantage in the calculation of the short-circuit tensor to omit nodes in radial lines and nodes which have only two lines terminating on them (intermediate nodes). These nodes have no effect on the open-circuit driving point and transfer impedances of the remaining nodes. The column matrix of open-circuit driving-point and transfer impedances pertaining to each of the omitted nodes can be easily calculated just prior to taking the fault unless there is mutual coupling to one of the lines which terminate on the node. For the case where there is mutual coupling, the nodes are included in the original short-circuit tensor.

If there is a normal fault at node N, the per-unit fault current is $1/Z_{N,N}$ for a 3-phase fault or $3/(Z_{N,N} + 2Z$ positive) for a single line-to-ground fault, where $Z_{N,N}$ is the open-circuit driving-point impedance at node N. For a closing-in fault, the column of the matrix pertaining to the faulted bus is modified for the "line open" condition and the fault current is then calculated the same as for the normal fault. An open-end fault is calculated in the same way as the closing fault except that the impedance of the line is added to the open-circuit driving-point impedance. Simultaneous faults at two nodes may be taken by closing a link of zero impedance between the two nodes and then faulting either node.

If desired, the short-circuit tensor may be modified to include the effect of constant-impedance loads. This is accomplished by establishing a load bus and closing the load links one at a time. Simultaneous faults at the load bus and the fault bus will then result in fault currents that include the effect of the loads.

Digest of paper 59-1164, "Digital Solution of Short-Circuit Currents for Networks Including Mutual Impedances," recommended by the AIEE System Engineering and Relays Committees and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill., Oct. 11-16, 1959. Published in AIEE *Power Apparatus and Systems*, Feb. 1960, pp. 1720-25.

A. L. Toalston is with Commonwealth Associates, Inc., Jackson, Mich.

A Practical Look at Information Theory

W. K. MacADAM
MEMBER AIEE

A discussion of the nature and basic modes of communication from the point of view of the modern techniques of handling, generating, storing, and transmitting knowledge or information in its manifold forms. The article is presented in two parts.

Part I

EFFICIENT communication has always been at a premium. Brevity is not only the soul of wit, it is downright labor saving. This is particularly important since human beings spend most of their waking hours in either the "receive" or "transmit" condition—more often the latter. While it is charitable to assume that what is transmitted is always information and always eagerly received, human laziness, at least, suggests some condensation of these gems of wisdom.

History records many instances of a brief but potent signal. What could be more meaningful than the "thumbs down" of the Roman emperor, particularly to the fallen gladiator? The cynic will suggest, of course, that the owner of the thumb was either too lazy or had his mouth too full of grapes to say "off with his head," or a more pungent Latin equivalent. Nevertheless, such emphasis on communication short cuts, whether from laziness or economic pressure, leads inevitably to a comparison of relative effectiveness of different communication methods.

To communicate effectively, we must do more than just be brief. There is the story of the worried husband who visited the psychiatrist about his wife. "Doctor," he said, "my wife talks all the time. As long as she is awake she keeps talking, and sometimes she even talks in her sleep." "It sounds bad" said the doctor, "What does she talk about?" "That's the whole trouble," said the husband, "She doesn't say." As will be seen later, we can characterize the lady's transmission by saying her signaling rate was high but the information content was low.

WHAT IS INFORMATION?

THE WORD "INFORMATION" means different things to different people. When the process of storing and transmitting knowledge is analyzed, however, the word is given a specialized meaning, convenient at least for present purposes.

In this particular field, information can be defined very broadly as "the indication of a condition." It is measured in terms of how specific we are compared with the variety with which our information may deal. For example, a baby knowing only one word can convey only limited information by this particular definition since he can make only one of two selections, namely, word or no word. On the other hand, a single word from a man with a large vocabulary contains much more information by our specialized definition, since he could have used any of thousands of words but made this particular choice. Furthermore, we measure information based on whether the outcome of the indication or selection is known in advance. Information should be newsworthy to have value.

Of course, even here we are giving a specialized definition of news, based on whether it was known in advance rather than on its impact or value.

For example, if we overheard a passer-by mention that an addition to the family was expected shortly, this would be technically just as much information as if our wife made a similar announcement. However, our reaction of course would be completely different. Science has no heart strings, it seems.

Information theory is a study of information primarily with a view of doing a better job of handling, generating, storing, and transmitting knowledge or information in any of its forms. Today this study is becoming more important because (a) people communicate more often; (b) we have progressively more information to learn and transmit in our lifetime; (c) we are in contact with more people; (d) we are doing more and more with computers and electronic transmission systems where we want to get the most for our money.

To explore this subject, let us first discuss the forms in which information exists and how to measure it. We can then look at the ways of converting it from one form to another to meet our particular requirements. Finally, we will take a few examples where information theory has brought us some really worthwhile advantages.

WAYS OF EXPRESSING INFORMATION

Having defined information as the indication of a condition, how do we express it? In what forms can it exist?

Actually, in a broad sense we use codes. The smallest building blocks of codes are called symbols or code

W. K. MacAdam is with the American Telephone and Telegraph Company, New York, N. Y.

This article is based on informal talks before several AIEE Section meetings.

elements. A significant assembly of code elements may be called a word. Furthermore, a significant group of words can be called a message. Of course, in utmost simplicity, one code element can convey a message.

Codes can consist of written or spoken symbols, pictures, arrangements of electrical impulses or even smoke signals. In this broad sense, speech is nothing but coded sound. There are elaborate codes and simple codes. These are the means we have of storing or transmitting information. We can even imagine that our thoughts are stored in our mind by coding nerve impulses.

Code elements can be sounds, numerals, alphabet letters, lights, colors, voltages, currents, mechanical states, or even one rock piled on another. To be a code these symbols must be significant. That is, they must mean something to some one.

Codes can be made up of continuous variations of a signal such as the height of mercury in a thermometer, representing temperature. On the other hand, they can be made up of discontinuous discrete elements such as alphabets, digits, or currents or voltages permitted to assume only stepped or so-called "quantized" values.

Since any quantized code elements can be considered digits of a number system, they are often called digital codes. In this way of thinking, the alphabet can be considered as a 26-digit code (or slightly more if spaces and punctuation are considered). In this case, the symbols are certainly quantized. No one ever heard of B and one half or W and two thirds.

Continuous codes are called analog because they are more or less representative of, or analogous to, some continuous function. The indication of a meter is a typical example.

One code can be converted to another if necessary to accomplish certain objectives. For example, simple codes are easier to send and recognize, but they take longer to transmit or store a given amount of information in a given system. Where time is important, complex codes are valuable. Where interference makes recognition difficult, simple codes are preferable.

Fig. 1 shows several different types of codes and the equivalent information expressed in either a simple or a complex code. As indicated in the upper section, when we go from a complex to a simple code, this is known as "coding upward," since the number of code elements is increased. The lower portion of Fig. 1 demonstrates the reverse process, which is known as "coding downward."

It can be seen from this illustration how simple codes take more symbols and hence more time or space for a particular message. On the other hand, it can also be seen that simple codes have greater recognizability. It was not difficult for Paul Revere to decipher "one if by land, two if by sea." If some one had waved a Chinese character at him, the countryside might have had a good sleep that night.

The 2-state or binary code is often much easier to handle in computer or electric circuits and has recently become quite popular in both computer and communi-

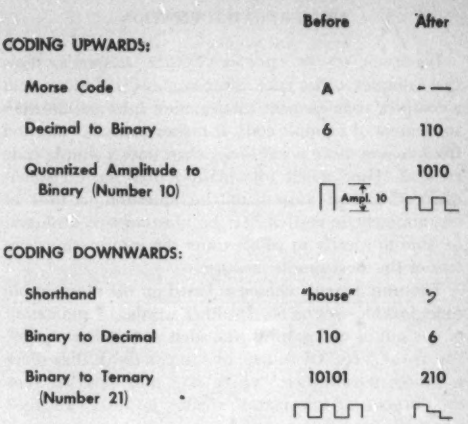


Fig. 1. Coding.

cation fields. The examples in Fig. 1 relate primarily to conversion from one digital or quantized code to another. However, conversion from analog to quantized codes is also possible. In this case, a 2-step process must be followed: (1) the analog signal at intervals must be sampled; (2) this sample must be rounded off to the nearest arbitrary quantity previously selected.

A voltage to the nearest volt could be read, for example, the value sent by morse or other digital code. Or we could have used numerous other schemes. In all cases, however, we have to sample and then quantize, or put in digital form, selecting the nearest available size.

At this point a very good question may be raised: "Why take a perfectly good analog signal and chop it to pieces by sampling and quantizing? Why not use it 'as is'?" Well, there are two factors that occasionally may make sampling and quantizing desirable. In the first place, the transmission or storage apparatus might be simplified. Secondly, in some cases there may be advantages from a noise control standpoint. We can look at these and other important factors in the quantizing process later.

There is another application of sampling alone that is valuable in communication. This is sampling for the purpose of time-sharing. It is useful when we want to handle a number of separate signals at the same time. If each signal is sampled briefly at intervals and in sequence, they can be handled in the same equipment on a time-sharing basis. This so-called time division multiplexing has advantages under some circumstances. It is probably a good idea to remember, however, that sampling and multiplexing is not strictly coding or a code conversion process. In some ways it can be considered an orderly and judicious process for throwing away information—hopefully, unnecessary information. It has the aspects of a scientific wastebasket.

MEASURING INFORMATION

INASMUCH AS THE CODE CONVERSION EXAMPLES show that complex codes take fewer symbols, it follows that a complex code element carries more information than an element of a simple code. It makes a specific selection from among more possibilities than does a simple code element. How much information does each element convey? For an answer to this question, a unit of measurement is needed. To be most useful, it should be able to specify in whole units the information content of the most simple message.

The unit actually chosen is based on the most simple code possible—yes or no. In other words, an indication of one out of two possibilities; such as "heads vs. tails," "on vs. off," etc. Of course, one might think that there are three possibilities: "yes," "no," and "maybe." For the purposes of information theory, however, we must be specific and "maybe" is not considered to be an informative answer.

If we use the information value of a simple "yes" or "no" as the unit of measurement, other more complex codes can be measured in terms of multiples of this basic yardstick. A one-out-of-two selection is the same as a selection from a 2-unit or binary numbering system. This supplies the name for our simple information measuring unit. It is called a "bit," an abbreviation of the words "binary digit."

This measuring stick can be applied to more complex selections than the one-out-of-two or yes–no variety. It turns out that any complex code can be broken down into a series of yes or no answers which progressively divide and subdivide the possibilities. The minimum number of these yes–no groupings needed to complete the selection equals the information content in bits.

A familiar example of this is the game "Twenty Questions." Another name for this is "Animal, Vegetable, or Mineral." The game involves guessing an object thought of by progressively narrowing the field with questions requiring a "yes" or "no" answer. It consists of making a selection from among thousands of possibilities and trying to come up with the specific selection in less than 20 questions.

A questioner must choose the questions carefully, however, so as not to waste them. For example, if we were playing the game and on the first of my 20 questions we asked, "Are you thinking of my watch?" you would probably say we were wasting this question since at this point the chances are quite unlikely that this was the object in mind. To get the most out of the first question, the possibilities must be progressively divided approximately in half. For example, we might say, "Is it living?" Instinctively, we have selected a question with an almost equal probability of a yes or no answer, and thus maximized the information in the answer.

As the field narrows down with successive questions, there eventually might be a time when the question, "Is it my watch?" might be appropriate with about a 50% chance of resulting in either a yes or a no. In other words, to cram the most information into a yes or no, there must be an even chance of each answer being appropriate. This further refines our yardstick, the bit.

We can define the bit as the maximum information possible in a single yes or no selection.

If each question in a game of "Twenty Questions" had an even chance of resulting in a yes or no, the information conveyed, in bits, would equal the minimum number of yes's or no's needed to make the selection.

In such a process, therefore, the questions should be so phrased that each yes or no progressively halves the number of remaining possibilities. Putting this statement in reverse, we can say:

> Each bit of information added to a message doubles the number of possible selections. One bit selects two, two bits four, three bits eight, etc. In other words, the progression goes up by power of two—two squared, two cubed, two to the fourth power, etc.

Thus:

> If the number of possible selections are known, the number of bits required will be the same as the power to which two must be raised in order to equal this number. In other words the logarithm to the base two of the selections determines the number of bits for equally likely selections.

If m is the possible number of selections that a symbol can represent, and we assume each selection equally probable, then

$$\text{Number of bits of information} = \log_2 m$$

When the symbols are not equally probable, less information is transmitted or represented by each symbol. For a particular symbol with individual probability of occurrence, p_i, the number of bits represented is[1]

$$H = -\sum_1^m p_i \log_2 p_i$$

Where

H = number of bits represented by individual symbol

While the derivation of this statement will not be shown, it would be reasonable if we check a few simple examples. First, let us assume that each symbol is equally probable. The chance of any particular symbol occurring is then $1/m$

$$H = -\sum_1^m \frac{1}{m} \log_2 \frac{1}{m}$$

There are m terms in this summation, each identical, or

$$H = -m\left(\frac{1}{m} \log_2 \frac{1}{m}\right) = +\log_2 m$$

The statement checks our original equation for equal probabilities. By the way, the term H is sometimes called "entropy," because its expression as a function of m looks like an equally confusing term in thermodynamics with this ridiculous name.

Now suppose the chances of a particular symbol were a certainty, as far as the receiver is concerned. Naturally, if you know what is to be sent, the message delivers no information. Let us see what our general statement says when we assume certainty, or a probability of 1.

$$H = \sum_1^m p_i \log_2 p_i = \sum_1^m \log 1 = 0$$

Likewise, if there is no chance ($p = 0$) of receiving a particular symbol, it will never be conveyed.

$$H = 0 \sum_1^m \log 0 = 0$$

So far so good. Science is vindicated and we might as well accept the statement and quit while we are ahead.

Up to this point, we have developed the fact that information exists in the form of codes and that each code element has an information content that can be measured in terms of bits. We found that if only two elements are possible in a code such as on-off, black-white, positive-negative, etc., the information value of each of these binary code elements is equal to one bit if the probabilities are equal. For the more complex codes we find that the information content of each code element increases and is equal to the logarithm to the base two of the possible number of code elements, assuming equal probabilities. For unequal probabilities, the information is reduced.

Using this concept, it may be interesting to see how many bits of information are contained in a letter of our alphabet. If any letter of a 26-letter alphabet were equally probable, the information in one letter would be the logarithm to the base two of 26 or 4.7 bits. Actually, all letters are not equally probable. When we apply the known probabilities for each letter, it develops that, on the average, each letter contains only 4.15 bits. Putting it another way, an 18-letter alphabet of uniform probability could do the same job as our less efficient 26-letter alphabet. This sober thought comes a little late in our civilization to expect immediate adoption. However, if any of you have difficulty with spelling, don't worry; you are just more efficient.

SAMPLING AND QUANTIZING

In discussing codes, it must be kept in mind that we have both continuous or analog codes and discrete or digital codes, and could convert from one to another. In going from analog to digital codes, as was pointed out, we first had to sample the analog signal at successive intervals and then to express or measure each sample in a digital code. In each of these steps, some of the information is lost, but there are situations in which this can be tolerated in view of the over-all advantage.

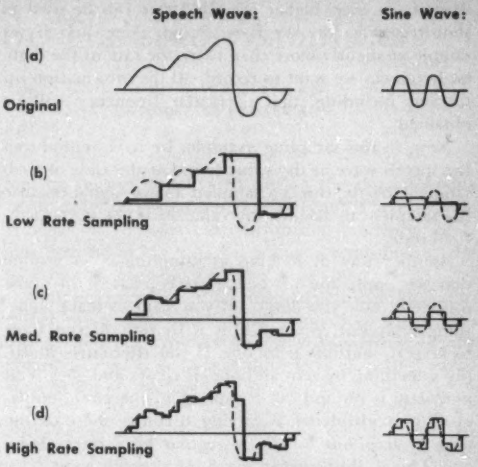


Fig. 2. Sampling by flat topping.

Let us first discuss the sampling process and see how much information is lost in sampling. Since an analog signal can theoretically assume any value, its information content in the absence of noise is theoretically infinite. By sampling, this information is reduced. The information content will be reduced further when we quantize the sampled values to arbitrary steps. The more often we sample, the more information we get. Similarly, the more possible units or quantum steps in our code, the more information we retain.

For example, speech is a more or less continuously variable signal. Suppose we sample a speech wave at various rates and see how much information is lost. Fig. 2 shows what happens in this case.

Here is where we get some more help from information theory or just plain common sense, if you will.[1] The information in speech is sensitive to loss of any of the frequency components. If we sample slowly, we miss the higher frequencies. They literally came and went while we were not looking.

Fig. 2a shows a speech wave and, directly to the right, a sine wave of the highest frequency of interest. This, and all frequencies below it, we want to preserve in the sampling process.

Fig. 2b shows what happens at low sampling rates. The wanted high frequency is missing. As pictured, the sampling rate is about equal to the frequency of the wanted frequency. Obviously, this rate is not high enough for our purpose.

In Fig. 2c the sampling rate is slightly higher than twice the maximum desired frequency. Here the rate is just high enough to generate a square wave of the highest frequency needed. The corners of this square wave can be rounded off with a low-pass filter or, if

desired, an even higher sampling rate can be used as shown in Fig. 2d. We have found, then, that if we sample at slightly more than twice the rate of the highest frequency we want to record, all the information up to, and including, that particular frequency will be obtained.

Now, in this sampling example, we have reproduced the speech wave at the value found at the time of each sample. Strictly, this is a sampled analog signal because the samples can assume any value. It is not yet a quantized code.

Another way of looking at sampling is to assume that we apply the mathematical equivalent of "now you see it, now you don't." If you want to make something disappear, you multiply it by zero. If you want to keep it, multiply it by one. If you alternately multiply something by zero and one, it comes and goes. You modulate it on and off. Sampling is, therefore, equivalent to multiplying a varying quantity most of the time by zero, but usually at regular brief intervals by one. This is illustrated in Fig. 3 for a speech wave.

This modulation process gives rise to products which include the original signal wave, the sampling frequency and sidebands, plus multiples of the sampling frequency, each with a pair of sidebands. Appropriately enough, it is called product modulation. It can also be called Pulse Amplitude Modulation, or PAM.[1]

It is important to note from Fig. 3 that a low-pass filter cutting off at approximately one half the sampling rate will permit the original signal wave to be recaptured. Remember, however, we go through this process only if we want to go to time division multiplex or to gain the advantages of quantized pulse transmission. The low-pass filter derivation of the original signal is made only at the end of the storage or transmission process.

Now after having looked at sampling, let us take the second step and convert our speech samples into a quantized code. This involves going from Pulse Amplitude Modulation to a general form of what is known as Pulse Code Modulation, or PCM. Fig. 4 shows how this can be done and demonstrates the effect of changing from a code with a few steps to one with many steps.

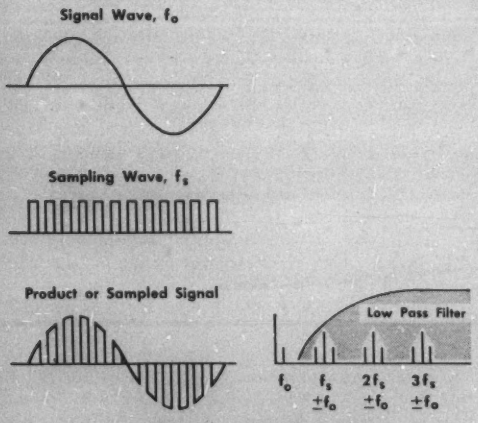


Fig. 3. Sampling viewed as product modulation.

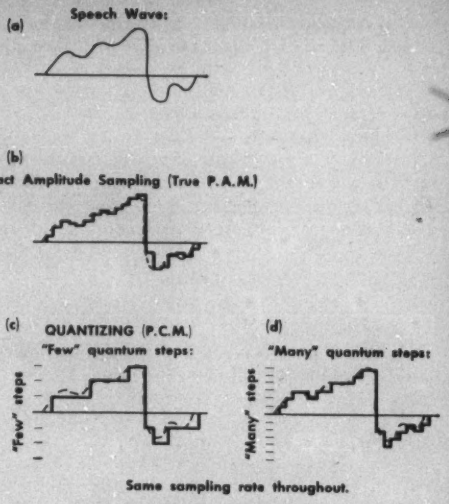


Fig. 4. Quantized sampled speech.

Fig. 4a represents an analog signal such as a portion of a speech wave. This can be sampled and flat-topped as shown in Fig. 4b, resulting in a series of PAM pulses that assume the exact height of the speech wave at the instant of sampling. In Fig. 4c these pulse heights have been quantized, forcing them to assume the nearest value corresponding to one of a series of uniform (in this case) stepped heights. In this figure, the "risers" of the steps are quite high. Notice, however, that the sampling rate is unchanged and the "treads" are the same width as before quantizing. They appear broader because the coarse quantizing puts several treads in a row at the same level before the change in the sampled wave is enough to justify one of the large risers.

The effect of using more possible quantizing steps is shown in Fig. 4d. Here the risers are lower although the sampling rate is unchanged. The resulting quantized wave follows the original speech much more closely than in Fig. 4c. Notice that quantizing puts jagged edges on the wave at each change of quantum step. This effect diminishes as the number of permissible steps increases with a corresponding reduction riser height. The granularity in the quantized or coded wave results in unwanted energy components known as "quantizing noise."

REFERENCE

1. Modulation Theory (book), H. S. Black. D. Van Nostrand Company, Princeton, N. J., 1953.

Self-Regulation in Magnetic-Transistor Amplifiers

C. E. HARDIES
ASSOCIATE MEMBER AIEE

R. L. VAN ALLEN
ASSOCIATE MEMBER AIEE

A CHARACTERISTIC is now available with a combination of magnetic amplifiers and transistors which heretofore has not been described. By a special utilization of this combination, an amplifier can be designed that has self-regulated output for variations in supply excitation. This characteristic is inherent to the circuitry and not accomplished by the addition of compensating networks.

In the "transactor"[1] and the "shunt-coupled magnetic amplifier,"[2] the output is taken essentially in parallel with the magnetic cores so that output exists during the time interval while the cores are changing flux. This parallel operation requires that current-limiting impedances be placed in series with the gate windings to limit the gate current after firing. Actually, the principle of having output occur during the prefiring interval rather than in the postfiring interval, as with conventional magnetic amplifiers, is the only item common to these all-magnetic devices and the magnetic-transistor amplifier.

Fig. 1 is a schematic diagram of the single-ended magnetic-transistor amplifier circuit. It contains a basic center-tapped magnetic amplifier and a transistor, together with their associated power and bias supplies.

The polarity of the transistor bias, acting through R_b, is negative to the base of the transistor and sufficient in magnitude to hold the transistor in its "on" or short-circuit condition under the most adverse conditions of load, excitation, and temperature. The polarity of the magnetic amplifier is such that its output is positive with respect to the base of the transistor. Thus, output is delivered via the switched transistor during the time intervals before the magnetic amplifier fires (prefiring), and no output is delivered during the time intervals when either core is saturated (postfiring). The transistor is held "off" or open-circuited during postfiring intervals because of the positive voltage established at the base by the magnetic amplifier.

Tests were conducted on this magnetic-transistor amplifier using both silicon and germanium transistors. Fig. 2 shows a typical transfer characteristic of the circuit in Fig. 1, as well as the effects of ±10% variation in supply voltage.

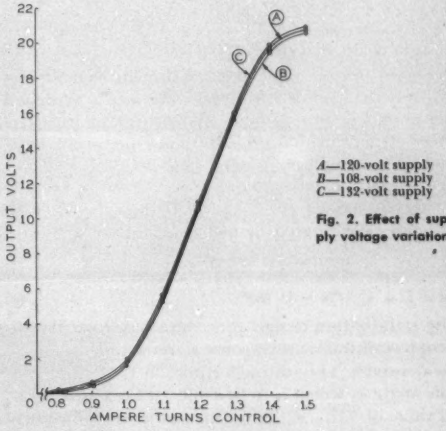
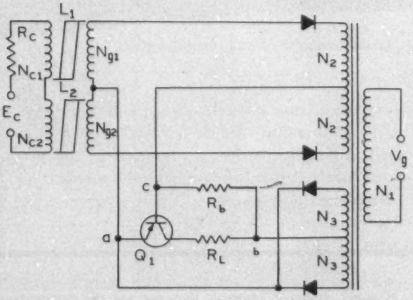


Fig. 2. Effect of supply voltage variation.

Using the single-ended magnetic-transistor as a building block, other circuits can be evolved readily. Both a polarity-reversing d-c magnetic-transistor amplifier and an a-c magnetic-transistor amplifier were investigated, and each exhibits the same desirable self-regulation characteristics for variations in supply voltage. In addition to this self-regulation, the circuitry provides high gain, temperature and frequency stability, and good load characteristics.



$V_g = 120$ volts, 60 cps
$N_1{:}N_2{:}N_3 = 120{:}6{:}30$
L_1, $L_2 = 50004\text{-}2A$
N_{g1}, $N_{g2} = 1{,}200$ turns
N_{c1} $N_{c2} = 1{,}000$ turns
$Q_1 = 2N241A$ transistor
$R_b = 2{,}000$ ohms
$R_L = 150$ ohms

Fig. 1. Magnetic-transistor amplifier, single-ended d-c.

REFERENCES

1. The Transactor: A Self-Saturated Transformer, Part I, A. S. Rosenstein. AIEE *Transactions*, pt. I *(Communication and Electronics)*, vol. 77, May 1958, pp. 129-42.

2. Shunt-Coupled Magnetic Amplifier Circuits, R. M. Hubbard. *Ibid.*, vol. 78, May 1959, pp. 124-31.

Digest of paper 59-1059, recommended by the AIEE Magnetic Amplifiers Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE-IRE Nonlinear Magnetics and Magnetic Amplifier Conference, Washington, D. C., Sept. 23-25, 1959. Published in AIEE *Communication and Electronics*, Jan. 1960, pp. 905-09.

C. E. Hardies is with Magnetics, Inc., Butler, Pa.; R. L. Van Allen, formerly with Magnetics, Inc., is now with the National Aeronautics and Space Administration, Washington, D. C.

Stabilization of Feedback Amplifiers

J. H. MULLIGAN, JR.
MEMBER AIEE

AMPLIFIERS and other dynamic systems can be classified as stable or unstable depending on the nature of their transient response. The stabilization problem for a feedback amplifier arises in the first place because of the presence of one or more of the roots of the characteristic equation in the right half of the complex frequency plane. It is useful, therefore, to consider the solution of the stabilization problem directly in terms of the transient response, rather than in terms of frequency response data such as gain and phase margins.

For a feedback amplifier to which the dominant term theory is applicable, the ratio of the deviations from unity in the normalized step-function response at two successive extreme values is

$$\eta = e^{-\pi \cot \psi_1} \tag{1}$$

where ψ_1 is the pole angle of the dominant pair of poles (Fig. 1). If the gain of a feedback amplifier is expressed in terms of the return ratio $T(s)$ of one of its active elements, then the closed-loop poles occur at those points in the complex plane for which

$$1 + T(s) = 0 \tag{2}$$

which may be expressed by the two conditions

$$| T(s) | = 1 \tag{3}$$

$$\text{Angle of } T(s) = \pm(2n + 1)\ 180° \tag{4}$$

The stabilization design procedure based on the direct control of transient response starts with a statement of the desired η. This, through equation 1, sets the value of pole angle ψ_1 which is to be achieved for a given midband value of $T(s)$, i.e., $T(0)$. One can then require that conditions (3) and (4) be satisfied for a point s on the line inclined ψ_1 degrees to the negative real axis when

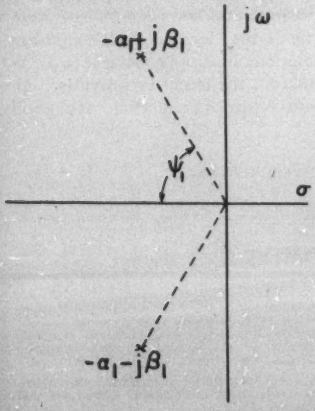


Fig. 1. Complex poles in closed-loop response to be produced by stabilization procedure.

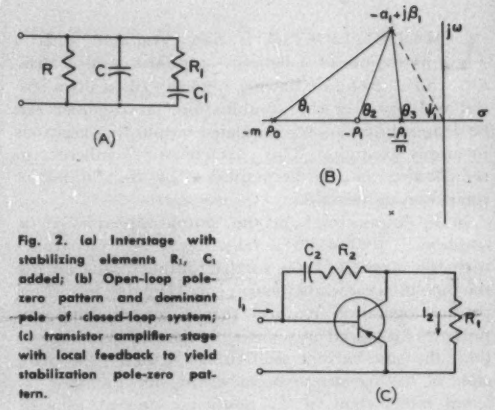


Fig. 2. (a) Interstage with stabilizing elements R_1, C_1 added; (b) Open-loop pole-zero pattern and dominant pole of closed-loop system; (c) transistor amplifier stage with local feedback to yield stabilization pole-zero pattern.

$T(0)$ has the desired design center value. Depending on the form of corrective networks employed to achieve stabilization, this may be enough information to achieve a unique solution or additional performance requirements may also be imposed.

Three examples are examined in connection with the discussion of the proposed technique. Stabilization by adding an external parallel capacitor is considered first, followed by a study of an amplifier with interstage networks of the form shown in Fig. 2(a). In terms of the variables shown in Fig. 2(b), condition (3) requires that θ_1, θ_2, and θ_3 satisfy the equation

$$\frac{\sin(\psi_1 + \theta_1)\ \sin(\psi_1 + \theta_3)}{\sin(\psi_1 + \theta_2)} = \frac{\sin \psi_1}{\sqrt[3]{T(0)}} \tag{5}$$

while condition (4) is expressed simply as

$$\theta_1 - \theta_2 + \theta_3 = \pm(2n + 1)60 \tag{6}$$

The passage from these conditions to the determination of element values in the stabilization networks is discussed at length. Brief consideration is also given to the use of local feedback to obtain pole-zero patterns for control of transient response. The properties of the transistor circuit shown in Fig. 2(c) are examined from this point of view.

Digest of paper 59-1151, "Transient Response and the Stabilization of Feedback Amplifiers," recommended by the AIEE Feedback Control Systems Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Chicago, Ill., Oct. 11-16, 1959. Published in AIEE *Applications and Industry*, Jan. 1960, pp. 495-503.

J. H. Mulligan, Jr. is with New York University, New York, N. Y.

INSTITUTE ACTIVITIES

Philadelphia Section Will Be Host to Summer General Meeting in Atlantic City

A FULL WEEK of technical and social activities awaits those who attend the AIEE Summer General Meeting, on June 19-24, in Atlantic City, N. J. The Philadelphia, Pa., Section will act as host for this meeting at one of the country's foremost seaside resorts. Headquarters will be at the Chalfonte-Haddon Hall Hotels on the boardwalk.

The activities will open on Sunday afternoon with an informal tea in the Garden Room of Chalfonte-Haddon Hall between 4:00 and 6:00 p.m. for the members of AIEE and their families.

Annual Meeting

The annual meeting will be held on Monday afternoon in the main ballroom of the Chalfonte-Haddon Hall, where the election of officers will be announced.

A feature of this session will be the presentation of the Lamme Medal to Dr. L. A. Kilgore of East Pittsburgh, Pa. Dr. Kilgore is being honored for meritorious achievements in the design of electric machinery; more specifically, for analysis of synchronous machine reactances, for inventions of special armature windings, and for inventions and designs related to large, adjustable-speed a-c motors.

AIRMEN of the Air Surveillance Section of the New York Air Defense Sector SAGE Direction Center keep an around-the-clock watch for air traffic within the boundaries of the New York Air Defense Sector's area of responsibility. This area encompasses 25 million Americans living from Delaware to Massachusetts, as well as a large segment of the Atlantic Ocean to the East. AIEE members will tour this vital defense center during the Summer General Meeting.

McGuire Air Force Base

Federal Aviation Agency

SIMULATOR PILOTS "fly" target generators of the new air traffic control simulator at the National Aviation Facilities Experimental Center of the Federal Aviation Agency's Bureau of Research and Development. AIEE members making the trip to this center in Atlantic City during the Summer General Meeting will have an opportunity to see the vast amount of experimental work being done to improve the safety of the Federal Airways.

Also at this meeting, E. B. Robertson will be awarded Honorary Membership in the AIEE.

Technical Program

An outstanding technical program has been planned for this meeting.

The technical program features sessions sponsored by most of the committees in the six technical divisions. Numbered among these are sessions to be held on Monday morning on power generation, electrical insulation, feedback control systems, and telegraph systems.

Tuesday sessions are scheduled on transmission and distribution, insulated conductors, magnetic amplifiers, nucleonics, feedback control systems, indicating and integrating instruments, recording and controlling instrumentation data communications, and broadcasting. The Section Delegates Conference is also scheduled for the full day.

On Wednesday, the committees are scheduling sessions on transmission and distribution, transformers, switchgear, solid-state devices, basic sciences, chemical industry, communication switching systems, land transportation, and special instruments and auxiliary apparatus.

Sessions on system engineering, land transportation, transmission and distribution, substations, computing devices, chemical industry, new activities and research, rotating machinery, radio commu-

TOD Forum

A session of the Forum of Technical Committee Chairmen will be held in connection with the Summer General Meeting in the Rutland Room of the Hotel Chalfonte-Haddon Hall, Atlantic City, N. J., at 7:30 p.m., Thursday, June 23, 1960.

By vote of the TOD (Technical Operations Department) Administrative Committee, this Forum will be "open house" to all members of the AIEE. Outgoing and incoming officers of the Institute and its committees are especially invited. Topics to be covered include publication matters and certain phases of co-operation between the AIEE and the Institute of Radio Engineers.

nication systems, and wire communication systems are scheduled for Thursday.

The meeting will close on Friday with sessions on system engineering, power system communications, rotating machinery, computing devices and semiconductor metallic rectifiers, and industrial and commercial power systems.

A panel discussion entitled "Exploring the Future of Direct Energy Conversion" is scheduled for 2 p.m. Thursday, June 23. The speakers will be: Dr. R. W. Pidd, research engineer, General Atomic Division of General Dynamics Corporation; Dr. S. W. Herwald, vice-president in charge of research, Westinghouse Electric Corporation; Dr. R. W. Blue, head of the solid-state department, Bendix Aviation Corporation; Dr. Irving Wolf, retired vice-president in charge of research, Radio Corporation of America Laboratories; and Dr. R. W. Porter, Engineering Services Division, General Electric Company.

It is expected that the panel will cover the present state of the art in direct energy conversion and the future prospects, and the speakers will express their opinions on how the research work needed to solve bottleneck problems can be promoted and financed.

In view of the fact that the American Society for Engineering Education (ASEE) is meeting at Purdue University, Lafayette, Ind., concurrently with the AIEE Summer General Meeting, the Education Committee of AIEE will hold no papers session in Atlantic City but will support the sessions of the Electrical Engineering Division of ASEE at Purdue.

Inspection Trips

Three inspection tours have been arranged as follows:

Sage Direction Center—McGuire Air Force Base, N. J. (Tuesday, June 21) This visit, to one of the country's vital air defense centers, will be limited to 30 persons.

Since security clearance must be obtained for this trip, members desiring to make the trip should write to T. H. Story, c/o Radio Corporation of America, Building 1-3, Camden 2, N. J., giving the following information: full name and address, name of employer, security clearance, if any. This information must be in Mr. Story's hands before June 7, 1960, so that the necessary clearances may be obtained. Reservations will be made in the order of receipt of the required information.

Federal Aviation Agency, Bureau of Research and Development, National Aviation Facilities Experimental Center—Atlantic City, N. J. (Wednesday, June 22) Ladies are invited.

Eddystone Station, Philadelphia Electric Company—Philadelphia, Pa. (Friday, June 24) Ladies are invited.

Social Activities

On Monday evening, June 20, a cabaret dance to which the ladies are invited will be held at Haddon Hall in the Vernon Room from 9:00 p.m. until 1:00 a.m. Refreshments will be available, dutch treat. Jimmy Marshall and the Top Tones Orchestra will be featured. There will be novelty and elimination dances for prizes. The price per ticket will be $2.50 at the ticket desk.

A card party will be held Tuesday evening, June 21, in the Rutland Room, Haddon Hall, starting at 8:00 p.m. This is informal, for ladies and gentlemen. There will be no admission charge. Refreshments will be available. Door prizes will be provided.

A dinner and show is scheduled for Wednesday evening, June 22. A social hour at 5:30 p.m. will precede the dinner at 6:45 p.m. and show to follow. The show will feature: singers, Earl Wrightson and Lois Hunt; comedian, Charles Mann; harmonica player, Alan Black; and dance team, Alfred and Lenore. The price per ticket will be $8.75 at the ticket desk.

For Thursday evening, June 23, a moonlight cruise is scheduled on Captain Starn's boat along the coast opposite Atlantic City. The price per ticket will be $1.75, available at the ticket desk. Boat trip tickets will be honored for either Tuesday or Thursday evening. Speed boat rides are available during the day.

The facilities of the Atlantic City Country Club will be available to golfing enthusiasts. The facilities include an 18-hole course and a small pitch and putt course. The greens fee is $5 during weekdays.

Half-day fishing trips leaving at 8:30 a.m. and returning at noon, or leaving at 12:30 p.m. and returning at 5:30 p.m., will be available at approximately $4 per person. All-day fishing trips leaving at intervals from 7:00 a.m. to 9:00 a.m. will be available for approximately $5 per person. Tackle may be rented.

The Ladies Committee from the Philadelphia and Atlantic City Auxiliaries, under the direction of Mrs. Cullen Pearce, has arranged a complete program of activities for the ladies which will be most enjoyable and entertaining.

On Sunday afternoon, an informal tea will be held between 4:00 and 6:00 p.m. in the Garden Room for AIEE members and their families.

The Ladies' Headquarters will be located on the sun porch on the lounge floor of Haddon Hall. Tickets for all events may be obtained in the Lobby.

Cards, the new swimming pool, and boat trips will be available to the ladies.

Special activities provided for teen agers include "coke" parties, bicycling, and splash parties.

A coffee hour for ladies will be held Monday, June 20, at 9:00 to 10:30 a.m. on the sun porch, the place to meet and form groups to walk on the boardwalk and plan other activities. Ladies will have a choice of the following two tours: Fischer Greenhouses or a trip to the Renault Winery. The buses will start leaving at 1:00 p.m. The tour will be followed by tea at the 18th Century Smithville Inn.

On Tuesday, June 21, from 9:00 to 10:30 a.m., a coffee hour for ladies will be held on the sun porch. An auxiliary meeting will be held at 10:30 a.m. to 12:00 noon. An authentic Hawaiian luncheon has been scheduled for 1:00 p.m. in the Vernon Room, and a card party, for 8:00 p.m., in the Rutland Room.

Breakfast on the sun deck and a showing of what's new in bathing suits and patio clothes has been planned for Wednesday, June 22, at 10:00 a.m. Special dinner and entertainment has been arranged. The Dutch treat cocktail hour will be held at 5:30 p.m. and dinner at 6:45 p.m. in the Carolina Room.

The coffee hour for ladies will be held Thursday and Friday, June 23 and 24, at 9:00 to 10:30 a.m. on the sun porch. A tour through Haddon Hall kitchens on Thursday will start at 10:30 a.m. from the Ladies' Headquarters on the sun porch.

Some clothing tips follow: Strolling on the boardwalk is fun, but a comfortable pair of walking shoes is a must for this pastime. The evening breezes are delightful, and a lightweight coat will be needed in order to enjoy them. Of course, a bathing suit is a necessity at the beach and the swimming pool.

The Chalfonte-Haddon Hall Hotels will act as Housing Bureau for this convention. A list of hotels and motels available is given in the April issue of *Electrical Engineering*, p. 334. All requests for room reservations for all the hotels and motels listed should be sent to Chalfonte-Haddon Hall.

Transportation

Direct air connections are provided by Allegheny Air Lines to Atlantic City from Philadelphia, Newark, N. J., and Washington, D. C.

Eastern Airlines provides service from New York, N. Y., and Washington to Atlantic City.

High speed and frequent express bus service is available from New York by the Lincoln Transport Company and the Public Service Company of New Jersey, from the New York bus terminal in downtown Manhattan.

From Philadelphia, bus service is provided from Public Service Company of New Jersey and Trailways Company from the Public Service Terminal at 13th and Filbert Sts.

Railroad service to and from Atlantic City is provided by the Pennsylvania-Reading Seashore Lines from Philadelphia. Delegates from distant cities should use Pennsylvania Railroad through-service and change to the seashore lines at North Philadelphia Station. Railroad service via

AIEE Future Meetings

World Power Conference
Instituto Nacional de Industria
Madrid, Spain
June 5-9, 1960

Summer General Meeting*
Chalfonte-Haddon Hall
Atlantic City, N. J.
June 19-24, 1960

AIEE-IRE-NBS Standards & Electronic Measurements Conference*
National Bureau of Standards Laboratory
Boulder, Colo.
June 21-22, 1960

International Federation of Automatic Control Convention
Moscow, Russia
June 27-July 6, 1960

Pacific General Meeting
El Cortez Hotel
San Diego, Calif.
August 8-12, 1960
(Final date for †TP—closed, ‡CP Syn.—closed, CPMs—June 3)

Aero-Space Transportation Conference
El Cortez Hotel
San Diego, Calif.
August 8-12, 1960
(Final date for †TP—closed, ‡CP Syn.—closed, CPMs—June 3)

AIEE-AIChE-IRE-ISA-ASME Joint Automatic Control Conference
Kresge Auditorium
Massachusetts Institute of Technology
Cambridge, Mass.
Sept. 6-9, 1960
(Final date for †TP—June 9, ‡CP Syn.—June 24, CPMs—July 5)

AIEE-ASME Engineering Management Conference
Morrison Hotel
Chicago, Ill.
September 14-16, 1960
(Final date for †TP—June 16, ‡CP Syn.—July 1, CPMs—July 11)

AIEE-IRE Industrial Electronics Symposium
Manger Hotel
Cleveland, Ohio
September 21-22, 1960
(Final date for †TP—June 23, ‡CP Syn.—July 8, CPMs—July 18)

AIEE-ASME National Power Conference
Bellevue-Stratford Hotel
Philadelphia, Pa.
September 21-23, 1960
(Final date for †TP—June 23, ‡CP Syn.—July 8, CPMs—July 18)

Petroleum Industry Conference
Skirvin Hotel
Oklahoma City, Okla.
September 25-28, 1960
(Final date for †TP—June 27, ‡CP Syn.—July 12, CPMs—July 22)

Fall General Meeting
Morrison Hotel
Chicago, Ill.
October 9-14, 1960
(Final date for †TP—June 10, ‡CP Syn.—July 21, CPMs—Aug. 5)

AIEE-IRE-EIA-SMPTE National Electronics Conference
Sherman Hotel
Chicago, Ill.
October 10-12, 1960
(Final date for †TP—July 12, ‡CP Syn.—July 27, CPMs—Aug. 5)

Nonlinear Magnetics and Magnetic Amplifier Conference
Bellevue-Stratford Hotel
Philadelphia, Pa.
October 26-28, 1960
(Final date for †TP—July 28, CPMs —July 15

AIEE-IRE-ISA Electrical Techniques in Medicine and Biology Conference
Sheraton-Park Hotel
Washington, D. C.
October 31—November 2, 1960
(Final date for †TP—Aug. 2, ‡CP Syn.—Aug. 17, CPMs—Aug. 26)

Power Industry Computer Application Conference
Chase Hotel
St. Louis, Mo.
November 9-11, 1960
(Final date for †TP—Aug. 11, ‡CP Syn.—Aug. 26, CPMs—Sept. 5)

AIEE-AIP Magnetism and Magnetic Materials Conference
Hotel New Yorker
New York, N. Y.
November 14-17, 1960
(Final date for †TP—Aug. 16, ‡CP Syn.—Aug. 31, CPMs—Sept. 9)

AIEE-NEMA Electrical Insulation Conference
Conrad Hilton Hotel
Chicago, Ill.
December 5-8, 1960
(Final date for †TP—Sept. 6, ‡CP Syn.—Sept. 21, CPMs—Sept. 30)

AIEE-IRE-ACM Eastern Joint Computer Conference
Hotel New Yorker
New York, N. Y.
December 11-14, 1960
(Final date for †TP—Sept. 12, ‡CP Syn.—Sept. 27, CPMs—Oct. 7)

AIEE-IRE-ASQC Reliability & Quality Control Conference
Bellevue-Stratford Hotel
January 9-11, 1961
(Final date for †TP—Oct. 11, ‡CP Syn.—Oct. 25, CPMs—Nov. 4)

Winter General Meeting
Hotel Statler
New York, N. Y.
January 29-February 3, 1961
(Final date for †TP—Oct 31, ‡CP Syn.—Nov. 10, CPMs—Nov. 25)

AIEE-IRE-U of P International Solid-State Circuits Conference
Philadelphia, Pa.
February 15-17, 1961
(Final date for †TP—Nov. 17, ‡CP Syn.—Dec. 2, CPMs—Dec. 12)

South East District Meeting
Jung Hotel
New Orleans, La.
April 5-7, 1961
(Final date for †TP—Jan. 5, CPMs —Jan. 30)

Materials Handling Conference
Chicago, Ill.
April 11-12, 1961
(Final date for †TP—Jan. 11, ‡CP Syn.—Jan. 26, CPMs—Feb. 6)

Cement Industry Conference
Sheraton-Cadillac Hotel
Detroit, Mich.
April 18-20, 1961
(Final date for †TP—Jan. 18, ‡CP Syn.—Feb. 2, CPMs—Feb. 13)

Great Lakes District Meeting
Hotel Pick-Nicolett
Minneapolis Minn.
April 19-21, 1961
(Final date for †TP—Jan. 19, CPMs —Feb. 13)

North Eastern District Meeting
Statler Hotel
Hartford, Conn.
May 17-19, 1961
(Final date for †TP—Feb. 16, CPMs—Mar. 13)

Summer General Meeting
Cornell University
Ithaca, N. Y.
June 18-23, 1961
(Final date for †TP—May 20, ‡CP Syn.—May 30, CPMs—Apr. 14)

*Final date for submitting papers—closed

†TP—Transactions Paper
‡CP Syn.—Conference Synopsis
CPMs—Conference Manuscript
DPMs—District Manuscript
(District Paper Synopses should be directed to the District Meeting Committee)

Transactions and conference papers must conform to the requirements in *Author's Guide*
For a copy, write to E. C. Day, AIEE, 33 W. 39th St., New York 18, N. Y.

PREPRINT PRICES

50¢ to Members
$1.00 to Nonmembers

ALL MAIL ORDERS must be accompanied by remittance in full or coupons.

COUPON BOOKS in $10 denominations may be purchased.

NUMBERED PAPERS only are available.

SEND ORDER and remittance to:
AIEE Order Department
33 West 39th Street.
New York 18, N. Y.

Washington, D. C., or Baltimore, Md., is available to delegates traveling from some Mid-Western cities at no extra cost. Delegates traveling in large groups should investigate special rates which may be obtained.

Good highways are available for delegates traveling by automobile. For those coming from the South, it is suggested that U.S. Route 40 be followed crossing over the Delaware Memorial Bridge below Wilmington, Del., and continuing on U.S. 40 to Atlantic City.

Those coming from the North should use the Garden State Parkway to its junction with U.S. 30, a few miles from Atlantic City.

Those traveling from the West will find it convenient to use the Pennsylvania turnpike to its junction with the Schuylkill Expressway at the Valley Forge interchange. Schuylkill Expressway is now completed through to the new Walt Whitman Bridge at Philadelphia and New Jersey Route 42 may then be followed to Atlantic City.

On Friday, June 24, buses will be provided for an inspection trip to the new Philadelphia Electric Generating Station, Eddystone, Pa Arrangements have been made for the handling of luggage on these buses and for stops on the return trip at Philadelphia International Airport and Pennsylvania Railroad 30th Street Station. Advance reservations for this service will be required.

Registration

The registration desk located in the lobby of Haddon Hall wil be open from 2:30 p.m. to 4:30 p.m. on Sunday and from 8:30 a.m. to 4:30 p.m. daily throughout the meeting. Members should register upon arrival and the registration fees are $6 for members, $10 for nonmembers, and $2 for ladies. Student members will not be charged a registration fee.

There will be no advance registration for the technical sessions, but those planning to participate in the social events and inspection trips are requested to return the cards which have been mailed to all members in order to assist the meeting officers in their plans for the various events. Cabaret dance and dinner show tickets must be paid for in advance. Remaining tickets will be sold on a first-come first-served basis.

Directors, officers, and delegates may receive their credentials at a special desk in the registration area.

The Committee for this meeting is composed of the following: S. R. Warren, Jr., general chairman; H. H. Sheppard, vice-chairman; B. H. Zacherle, treasurer; D. B. Smith, chairman, Finance Committee; W. R. Clark, C. S. Collier, D. L. Greene, R. S. Hewett, A. E. Pringle II, G. B. Schleicher, and M. L. Stoughton, members at large; R. L. Halberstadt, Arrangements Committee chairman; C. H. Rice, Entertainment Committee chairman; W. P. Wills, Hotel Committee chairman; T. H. Story, Inspection Trips chairman; Mrs. Cullen Pearce, Ladies' Committee chairman; R. T. Ferris, Publicity Committee chairman; C. S. Dayton, Registration Committee chairman; T. W. Metz, Sports Committee chairman; E. M. Callender, Students Committee chairman; R. G. Lex, Jr., Technical Program Committee chairman; and S. V. Smith, Transportation Committee chairman.

Technical Papers Listed

The tentative technical program follows:

Monday, June 20th

10:00 a.m. Morning Sessions

Round Table Discussion on Data Handling and Computer Application Inside Power Plants

CP.* Automatic Data Processing in Palo Seco Steam Plant Puerto Rico Water Resources Authority. *R. R. Ramirez, M. Iriarte,* Puerto Rico Water Resources Authority; *R. R. Tressler,* Jackson & Moreland, Inc.

CP.* Data Handling and Computer Equipment for Power Stations. *G. Barney,* Stone & Webster Engineering Corp.

CP.* One Approach to Data Handling, Reduction, and Analysis in Power Plant Practice. *S. A. Lyon,* New York State Electric & Gas Corp.

CP.* Application of Data Logging Equipment to Power Plants. *E. G. Norell,* Sargent & Lundy

CP.* Data Handling and Computer Applications for Power Plants.

Electrical Insulation

60-857. Electrical Tracking Resistance of Polymers. *G. M. L. Sommerman,* Westinghouse Electric Corp.

60-858. Insulat. n System for Naval Shipboard Motors Intermittently Submersed. *C. B. Hackney,* Allis-Chalmers Manufacturing Co.; *H. P. Walker,* U.S. Navy Bureau of Ships (re-presented for discussion only)

Nonlinear Systems and Components

60-862. Nonlinear Servomechanism of Limited Dynamic Range. *R. L. Moruzzi,* Worcester Polytechnic Institute; *F. B. Tuteur,* Yale University

60-863. Analyzing the Transient Response of a Nonlinear Servo System by the Phase Plane Method. *W. A. Stein* (deceased, formerly with U.S. Naval Postgraduate School); Presented by *G. J. Thaler,* U.S. Naval Postgraduate School

60-865. A Transformation Method for the Study of Nonlinear Components and its Application in Control Systems. *C. Lakshmi-Bai,* Indian Institute of Science

CP60-864. Application of Silicon Controlled Rectifiers in a Transistorized High-Response D-C Servo System. *C. Cantor,* U.S. Naval Weapons Plant

60-111. On a Systematic Approximation to the Partition Method for Analysis of a Class of Nonlinear Systems. *Y. H. Ku, J. H. Dietz,* University of Pennsylvania; *A. A. Wolf,* Stromberg-Carlson Co. (re-presented for discussion only)

Telegraph Systems

CP60-786. The *83B2* Teletypewriter Selective Calling Systems. *C. J. Volaw, A. L. Whitman,* Bell Telephone Labs., Inc.

60-861. Teletypewriter Selective Calling Applied to Automatic Airlines Reservations. *R. W. Bratschi,* Remington Rand Univac; *W. D. Pennington,* American Telephone & Telegraph Co.; *A. L. Whitman,* Bell Telephone Labs., Inc.

60-770. An Electronic Teleprinter Distributor. *N. N. Biswas, H. Rakshit,* University of Wisconsin

60-789. High-Voltage Static Eliminators for Teletypewriters. *L. A. Jonas,* Bell Telephone Labs., Inc.; *F. E. Hanscom,* The Portland Co.

2:00 p.m. General Session

Tuesday, June 21

9:00 a.m. Morning Sessions

Switching Surges and Insulators

60-829. 115-Kv Bus Switching Surges. *L. C. Weber,* Northern States Power Co.; *L. C. Elliott, H. M. Smith,* Westinghouse Electric Corp.

60-831. Effect of Rainfall Resistivity on 60-Cycle Wet Flashover of Suspension Insulators. *R. J. Mather, M. G. Poland,* Bonneville Power Administration

CP.* A Proposal for a Realistic Wet Test. *H. R. Armstrong,* The Detroit Edison Co.

CP.* Numerical Factors Influencing Transformer Overvoltages Caused by Chapping of Magnetizing Current. *M. W Jablonski,* Cornell University

Insulated Conductors

Note: The following paper will be available to members at $2 per copy and to nonmembers at $4 per copy.

60-785. Soil Thermal Characteristics in Relation to Underground Power Cables. A Report of the AIEE Insulated Conductors Committee, AIEE-ICC Subcommittee No. 14. R. W. Burrell, chairman

Part I: Introduction—Problem and Objective. *R. J. Wiseman,* The Okonite Co.; *R. W. Burrell,* Consolidated Edison Co. of New York, Inc.

Part II: Soil Types—Identification and Physical Properties. *W. A. Del Mar,* Phelps-Dodge Copper Products Corp.; *R. W. Burrell,* Consolidated Edison Co. of New York, Inc.; *C. A. Bauer,* Commonwealth Edison Co.

Part III: Soil Moisture Characteristics *L. H. Fink,* Philadelphia Electric Co.

Part IV: Soil Thermal Resistivity —Typical Field Values and Calculating Formulas. *W. A. Sinclair,* The Detroit Edison Co.; *F. H. Buller,* Anaconda Wire and Cable Co.; *C. B. Benham,* Florida Power Corp.

Magnetic Amplifiers

60-872. Theory of 3-Phase Bridge Magnetic

*Conference papers will not be reprinted by the Institute; however, they may be available at the meeting at the discretion of the author.

Amplifier—Part II: The Time Constant. *H. F. Storm, C. W. Flairty*, General Electric Co.

60-873. Magnetization in Tape-Wound Cores. *R. C. Baker*, Yale University (re-presented for discussion only)

CP.* Tunnel Diode-Saturable Reactor Control Element—Part I. *R. E. Morgan*, General Electric Co.

60-788. Theory and Operation of a Cross-Field Magnetic Modulator. *D. W. Boensel*, California Institute of Technology (re-presented for discussion only)

CP60-874. Initiation of Flux Reversal in Magnetic Amplifier Cores. *F. J. Friedlaender*, Purdue University; *I. P. Leliakov*, General Electric Co.

60-875. Time Response Constant and Transfer Function of Magnetic Amplifiers. *E. W. Manteuffel*, General Electric Co. (re-presented for discussion only)

Nuclear Safety

CP60-869. Safeguard Considerations of the Piqua Organic Moderated Reactor. *J. Jacobson*, Atomics International

CP.* Safety Problems Relating to Nuclear Vehicles. *J. E. Standefer*, Chance Vought Aircraft

CP.* Reactor Safeguards. *E. Case*, U.S. Atomic Energy Commission

CP60-896. Shipboard Radiological Safety as Related to Nuclear Submarines. *J. F. Logsdon*, Electric Boat Co.

Analysis Techniques for Control Systems

CP60-866. Analysis to Finite Pulse Systems with a Periodically Varying Sampling Rate and Pulse Width. *E. I. Jury, T. Nishimura*, University of California

60-867. Sampled-Data Control System with Two Digital Processing Units. *C. Hung*, New York University

60-779. Design of Servo Compensation Based on the Root Locus Approach. *E. R. Ross*, Department of National Defense (Navy); *T. C. Warren*, U.S. Navy; *G. J. Thaler*, U.S. Naval Postgraduate School

CP60-868. Fluid Servomechanisms by the Stability Factor Method. *A. G. Fonda*, Bell Aircraft Corp.

58-1362. A Digital Nuclear Reactor Control System. *E. P. Gyftopoulos*, Massachusetts Institute of Technology; *P. M. Coble*, Stevens, Davis, Miller, & Mosher (re-presented for discussion only)

Instrumentation

CP60-882. A Single-Channel Digital Data Recorder. *W. J. Schmidt, E. A. Sagan*, Westinghouse Electric Corp.

CP60-885. Transistorized Draw Speed Indicator for the Paper Industry. *W. J. Schmidt, S. Salowe*, Westinghouse Electric Corp.

59-160. A Transistor Oscillator Limit Switch for Indicating and Recording Instruments. *J. T. Wintermute, S. G. Hayter*, Westinghouse Electric Corp. (re-presented for discussion only)

CP60-806. Miniaturized Current Transformers for Multirange Operation of Milliammeter Ink Recorders. *W. A. Geyger*, U.S. Naval Ordnance Lab.

Data Communications and Telegraph Sytems

CP.* A Card-to-Magnetic-Tape Data System. *F. David, C. J. Zarcone, R. L. Wolf*, Stromberg-Carlson Telephone Co.

CP.* Evaluation of Low-Frequency Impairment in Baseband Data Links. *R. A. Gibby*, Bell Telephone Labs., Inc.

CP60-790. "Datacom Unit," an Experimental Data Transmission Subset. *R. E. Stoffels*, Automatic Electric Co., Inc.

CP60-891. Binary Decision Feedback with Envelope Detection. *J. J. Metzner, K. C. Morgan*, New York University

Section Delegates Conference

2:00 p.m. Afternoon Sessions

Distribution

CP60-832. Determination of Economical Distribution Substation Size. *J. A. Smith*, General Electric Co.

CP60-833. Economics of Primary Distribution Voltages of 4.16 through 34.5 Kv. *J. A. Smith*, General Electric Co.

CP60-834. The Influence of Transmission on Distribution System Cost. *D. N. Reps, J. E. McNabb*, Westinghouse Electric Corp.

Insulated Conductors

Note: The following paper will be available to members at $2 per copy and to nonmembers at $4 per copy.

60-785. Soil Thermal Characteristics in Relation to Underground Power Cables. A Report of the AIEE Insulation Conductors Committee, AIEE-ICC Subcommittee No. 14. R. W. Burrell, chairman

Part V: Practical Application—Trench Design and Construction. *A. S. Brookes*, Public Service Electric & Gas Co.; *M. H. McGrath*, General Cable Corp.

Part VI: Measurement Techniques. *A. W. W. Cameron*, Hydro-Electric Power Commission of Ontario; *A. S. Brookes*, Public Service Electric & Gas Co.

60-809. Long Time Heat Runs on Underground Cable in a Sand Hill. *T. A. Balaska, A. L. McKean, E. J. Merrell*, Phelps Dodge Copper Products Corp.

60-810. Seasonal Variation in Soil Thermal Resistivity. *G. W. N. Fitzgerald, J. W. Newall*, Hydro-Electric Power Commission of Ontario

Magnetic Amplifiers

60-784. Analysis and Optimization of the Bridge Magnetic Servo Amplifier with True Motor Load. *J. M. Walsh*, J. W. Fecker, Inc.; *Z. H. Meiksin*, University of Pittsburgh

60-870. High-Power Pulse Generation Using Semiconductors and Magnetic Cores. *E. M. Lassiter*, Chance Vought Aircraft; *P. R. Johannessen*, Sylvania Applied Research Lab.; *R. H. Spencer*, Massachusetts Institute of Technology (re-printed for discussion only)

CP.* Capacitor Selection for Controlled Rectifier Circuits. *J. D. Harnden, Jr., R. L. Watts*, General Electric Co.

60-783. Static Control for a Mechanically Regulated D-C Supply. *H. J. Abrams, J. F. Brubaker*, Westinghouse Electric Corp. (re-presented for discussion only)

CP60-900. The Magnetic Amplifier as a Circuit Dual. *D. A. Robinson*, Airpax Electronics Inc.

Nuclear Safety

CP.* Safety Factors in Fast Reactor Design. *C. E. Branyon*, Atomic Power Development Associates

CP60-876. Some Experimental Studies of Safety of Outer Containment Structures for Nuclear Reactors. *J. W. Hanna*, Ballistic Research Labs.

CP.* SPERT Reactor Safety Program. *G. O. Bright*, Phillips Petroleum Co.

Feedback Control Systems

Recording and Controlling Instrumentation

Broadcasting

CP60-811. New TV Network Switching Facilities. *A. E. Bachelet, C. A. Collins, E. R. Taylor*, Bell Telephone Labs., Inc.

CP.* Videotape Problems with Various International System Standards. *J. R. Popkin-Clurman*, Telechrome Manufacturing Corp.

CP.* Low Light Level TV. *H. F. Stearns*, General Electric Co.

60-812. Production Design Considerations in Television Chassis Sweep Interference Reduction. *G. W. Carson*, Zenith Radio Corp.

Section Delegates Conference

Wednesday, June 22

9:00 a.m. Morning Sessions

Transmission and Distribution, System Engineering

CP60-776. Determination of Generation Schedules by the Use of the Network Analyzer *S. Despotovic*, Beograde, Yugoslavia

60-777. A Fast Method of Development of Transmission Loss Formula. *S. Despotovic*, Beograde, Yugoslavia

60-838 A Digital Computer Program for Secondary Network Analysis. *R. F. Cook, J. N. Powers*, Westinghouse Electric Corp.

CP60-839. Computer Analysis of 32-Step Voltage Regulator Performance. *A. C. Dolbec, M. W. Gangel, W. W. Green*, General Electric Co.; *A. J. Wood*, Hughes Aircraft Co. (formerly with General Electric Co.)

Transformers

CP.* A New and Improved Heat Stabilized Insulation. *M. G. Leonard, A. M. Lockie, J. G. Ford*, Westinghouse Electric Corp.

CP.* Temperature Capabilities of a Modern Transformer Insulation System. *W. C. Farneth, W. H. Mutschler, Jr.*, Allis-Chalmers Manufacturing Co.

CP.* New Aluminum Low-Voltage Connector for Distribution Transformers. *W. M. Armstrong*, Allis-Chalmers Manufacturing Co.

60-827. A Method of Calculating the Voltage Distribution of Cascade Connected Testing Transformers. *H. E. Schaffer*, Westinghouse Electric Corp.

CP.* A New Regulator for Distribution Transformers. *J. J. Astleford*, Westinghouse Electric Corp.

Micro Systems Electronics—I

CP60-877. Multiple Collector Semiconductor Devices in Molecular Electronics. *D. P. Kennedy, S. Gilman*, International Business Machines Corp., *S. Gilman*, General Electric Co.

CP60-878. The Logic Potential of Molecular Electronics in the Multi-Collector Transistor. *J. Earle*, International Business Machines Corp.

CP.* Logic Switches. *G. Strull, M. N. Guiliano, D. D. O'Sullivan*, Westinghouse Electric Corp.

CP.* An Integrated Binary Adder. *M. E. Szekely, S. M. Marcus, J. T. Wallmark*, Radio Corporation of America Labs.

Basic Sciences

CP60-884. Supermendur—a Space Age Magnetic Alloy. *M. Lauriente, R. E. Lee*

60-782. The Properties of Pole and Zero Locations for Nondecreasing Step Responses. *A. M. Zemanian*, New York University

60-879. Analysis of Transcendental Nonlinear Systems. *A. A. Wolf*, Stromberg-Carlson Co.

CP60-880. Obtaining Acceleration Spectral Density Curves Directly from the Sinusoidal XY Plot. *R. B. Kaplan*, American Bosch Arma Corp.

CP60-881. Series Connected Saturable Reactor with Direct Output and Inductive, Back EMF Load. *R. R. Wood*, The

Ohio State University; *S. P. Jackson*, Power Equipment Co.

Underground and Equipment Corrosion

CP.* Underground and Equipment Corrosion Due to Dissimilar Metals in Soils and Solutions. *M. G. Miller*, Upper Saddle River, N.J.

Communications Switching—I

60-788. Automation in Switching Equipment Engineering. *M. E. Hacker, C. M. Davis*, General Telephone Co. of California

60-817. Automation of Telephone Switching Equipment Engineering. *L. W. Blumer*, Northwestern Bell Telephone Co.; *G. E. Reifenstuhl*, Western Electric Co.; *N. E. List*, Michigan Bell Telephone Co.

CP60-818. Development of Special Positions for Handling Person-to-Person, Collect, and Credit Card Calls. *L. Frericks*, New York Telephone Co.

60-819. Reflections on the Traffic Usage Recorder with Emphasis on Traffic Engineering. *R. A. Bauerfeld*, The Southern New England Telephone Co.

2:00 p.m. Afternoon Sessions

Radio Influences and Conductors

60-848. The Calculation of Attenuation Constants for Radio Noise Analysis Overhead Lines. *G. E. Adams, L. O. Barthold*, General Electric Co.

60-775. The Pulses and Radio Influence Voltage of Power Frequency Corona. *A. S. Denholm*, High Voltage Engineering Corp.

CP60-840. Emissivity of Weathered Conductors after Service in Rural and Industrial Environments. *W. S. Rigdon, R. J. Grosh, W. B. Cottingham*, Purdue University; *H. E. Touse*, ALCOA Research Labs.

CP60-841. The Prediction of Aeolian Vibration Fatigue Damage of Transmission Line Cables. *R. F. Steidel, Jr.*, University of California

Transformers

CP.* Detection of Incipient Faults in Transformers by Gas Analysis. *T. S. Pugh*, American Electric Power Service Corp.; *H. H. Wagner*, McGraw-Edison Co.

59-1133. Phase—Isolated LTC ransformers. *F. P. Kasper*, Oklahoma Gas & Electric Co.; *J. S. Holtzinger, G. A. Wilson*, McGraw-Edison Co. (re-presented for discussion only)

60-828. Bibliography on Transformer Noise. AIEE Subcommittee on Audible Sound, Working Group on Technical Investigations. *M. W. Schulz, Jr.*, chairman.

60-238. Sound Barrier Walls for Transformers. AIEE Committee Report. *M. W. Schulz, Jr.*, chairman

Micro Systems Electronics—II

CP.* Audio Amplifiers Functional Electronic Block. *J. Husher*, Westinghouse Electric Corp.

CP.* Semiconductor Networks—A Realistic Approach to Micro-Electronics. *R. C. Lee*, Texas Instrument

CP.* Controlled Deposition of Thin-Volume Circuit Elements for Micro Circuits. *J. Blank*, General Electric Co.

CP.* Vapor-Deposited Single-Crystal Germanium Layers for Use in Micro-System Electronics. *R. P. Ruth*, Bendix Corp.

Land Transportation

CP60-808. Economics of Electric Traction in Philadelphia. *E. L. Tennyson*, City of Philadelphia, Dept. of Public Property

CP.* Philadelphia Welcomes the First Fleet of Stainless Steel Rapid Transit Cars. *G. H. Smith*, Philadelphia Transportation Co.

CP.* The First Fleet of Stainless Steel Rapid Transit Cars. *L. F. Reynolds*, The Budd Co.

Chemical Industry

CP.* Electric Vehicles. *B. F. Bennett*, General Electric Co.

CP.* Electric Vehicles, Batter Power Supplies. *H. C. Riggs*, Electric Storage Battery Co.

CP.* Nickel Cadmium Batteries. *B. Eilbeck*, Nife Inc.

60-849. Aircraft Storage Batteries. *W. J. Hamer*, National Bureau of Standards (re-presented for discussion only)

60-895. A Constant Voltage Battery Charger. *C. H. Leet*, The Electric Storage Battery Co.; *W. Zug*, The Electric Products Co. (re-presented for discussion only)

Special Instruments and Auxiliary Apparatus

60-660. Portable Dynamic Electronic Speed-Torque Indicator. *H. R. Weed*, Ohio State University

60-835. Magnetic Flux Pattern Instrumentation Using Hall Probes. *H. Hollitscher*, Canadian General Electric Co. Ltd.

CP60-836. A New Naval Facility for Measuring Low-Level Magnetic Fields. *W. W. Anderson*, U.S. Naval Engineering Experiment Station

CP.* Electronic Training and Control Device as Used in Short-Circuit Testing. *H. W. Mikulecky*, McGraw Edison Co.

Communications Switching—II

60-820. Voice Immunity Tone Operated Switching Centers. *J. H. Guenther*, Litton Industries; *J. Shirman*, Stromberg-Carlson Co.

CP60-821. A Mechanical Presentation of a Transportable Electric Switching System. *G. S. Hasman*, Stromberg-Carlson Co.

60-822. Synthesis of a Resonant Transfer Filter as Applied to a Time Division Multiplex System. *P. J. May, T. M. Stump*, Stromberg-Carlson Co.

Thursday, June 23

9:00 a.m. Morning Sessions

Economics of Generator Shutdown

CP60-894. Economics of Generator Shutdown and Start-up. *R. T. Drew*, Niagara Mohawk Power Corp.

CP.* Scheduling Generating Capacity for Minimum System Loads. *A. C. Hartranft, F. H. Light*, Philadelphia Electric Co.

CP60-847. Factors Controlling Shutdowns in Light Load Periods. *H. C. Otten, M. Salvage, M. J. Steinberg*, Consolidated Edison Co. of New York, Inc.

CP.* Short-Time Shutdown of Steam Turbine Generator Units. *A. P. Hayward, R. M. Buchanan*, Duquesne Light Co

Land Transportation

CP60-886. Progress Report on Traction Motor Insulation. *J. K. Wentz, R. M. Lukes*, General Electric Co.

CP.* Extension of Epoxy Insulation to Light Traction Motors. *J. W. Clokey, J. R. Shirley*, Westinghouse Electric Corp.

CP. Diesel-Electric Locomotive Excitation Systems. *A. V. Johansson*, General Electric Co.

CP.* Static Voltage Regulators. *R. K. Allen, W. B. Zelina*, General Electric Co.

Distribution

CP60-842. Voltage Nomenclature — Secondary and Utilization Systems. *A. S. Anderson*, Ebasco Services Inc.

CP60-843. Distribution System Planning through Optimized Design III—Choice of Voltage-Regulation Point in the System. *R. F. Lawrence, D. N. Reps, A. D. Patton*, Westinghouse Electric Corp.

60-855. Correlation of Radial Distribution Feeder Regulation Variables and Determination of Regulator Voltage Control Limits. *C. J. Couy*, Duquesne Light Co.

CP60-883. Single-Phase Single-Wire Transmission for Rural Electrification. *R. W. Atkinson, R. W. Garg*, Bihar Institute of Technology

Substations

CP.* Public Relations Improved by Decorative Substation Enclosures. *J. D. Hoffman*, High Voltage Equipment Co.

CP60-796. The Application of Mobile Substations to the San Diego Gas & Electric System. *C. D. Mack*, San Diego Gas & Electric Co.

60-797. An Indoor 138/26/13-Kv Switching Station for Newark, N.J. *R. N. Southgate*, Public Service Electric & Gas Co.

60-798. Omaha Public Power District 161-Kv Substation Design. *H. C. Sanders*, Omaha Public Power District

Computer Simulation and Components

CP60-802. Computer Simulation of Magnetic Character Recognition Logic. *A. Hamburgen, Mar in Schatzoff*, International Business Machines Corp.

CP60-803. The Use of Z Transforms for a Digital Simulation of a Continuous Transfer Function. *P. A. Stephens, Jr.*, Litton Industries (formerly with Hughes Systems Development Labs.)

CP60-804. An Improved Ferro-Resonant Transformer. *P. Essinger, O. M. Baycura*, International Business Machines Corp.

CP60-805. A System of Threshold and Analog Logic for Variable-Radix Adders and Other Computer Organs. *J. Sklansky*, Radio Corporation of America Labs.

CP60-860. Fault Calculations for a Radial Shipboard Distribution System with a Digital Computer. *S. M. Scarborough, J. C. McKee, Jr.*, Mississippi State University

Wire Communication Systems

CP60-888. O-OJ Carrier Junction Equipment. *T. G. Fellows*, Northern Electric Co

CP60-813. A Transistor Automatic Gain Control System for Audio Frequencies *J. Shireman*, Stromberg-Carlson Co.

60-814. E6 Telephone Repeater Background, Description, and Theory of Operation. *E. J. Doyle, T. J. Talley*, American Telephone & Telegraph Co.; *L. Horngraf, L. Petersen, J. O. Smethurst*, Bell Telephone Labs. Inc. (re-presented for discussion only)

60-815 Wire Line and Carrier Communications on the Union Pacific Railroad *C. O. Jett*, Union Pacific Railroad (re-presented for discussion only)

60-816 A Voice-Band Transmission Set Using Swept-Band Techniques. *W. C. Lent*, Hallamore Electronics Co. (re-presented for discussion only)

CP60-823 The Interpretation of Results Obtained with a Swept-Band Transmission Measuring Set. *S. L. Wilson, Jr.*, Siegler Corp.

2:00 p.m. Afternoon Session

Economics of Hydro Thermal Systems Operation

60-837. Hydro-Thermal Economic Scheduling —I Solution by Incremental Dynamic Programming. *B. Bernholtz, L. J. Graham*, The Hydro Electric Power Commission of Ontario (re-presented for discussion only)

CP.* Hydro-Thermal Economic Scheduling—II Extension of Basic Theory. *B. Bernholtz, L. J. Graham,* The Hydro-Electric Power Commission of Ontario

CP60-890. Hydroelectric Generation Scheduling. *L. G. Peck,* Arthur D. Little, Inc.

60-787. Forced Generation Outage Investigations for the Northwest Power Pool. *H. U. Brown III,* Puget Sound Power & Light Co.; *L. A. Dean,* Bonneville Power Administration; *A. R. Caprez,* Light Division of the Dept. of Public Utilities, Tacoma

CP60-844. Incremental Cost of Water Power. *S. Stage, Y. Larsson,* South Sweden Power Co.

Switchgear-Substations

CP60-824. Technical and Economic Features of a 120/12/4-Kv Hydro-Quebec Substation. *J. Reist,* Quebec Hydro-Electric Commission

60-825. Current Asymmetry in Resistance-Reactance Circuits. *E. T. B. Gross,* Illinois Institute of Technology; *R. L. Kuntzendorf,* Commonwealth Edison Co.

60-826. Switching of 138-Kv Cable on 69-Kv Side of Transformer. *E. L. Michelson,* Commonwealth Edison Co.; *H. E. Lokay,* Westinghouse Electric Corp.

CP60-893. Joining Copper Bus Bars. *M. Brenner,* Penn-Union Electric Corp.

Rotating Machinery

60-772. Possibility of Reversing Single-Phase Squirrel Cage Induction Motors by Reversing the Terminal Supply Voltage. *A. K. Das Gupta,* Illinois Institute of Technology

CP60-771. The Design of High-Voltage Squirrel Cage Induction Motors on a Digital Computer to Meet Fixed Specifications. *P. H. Conceicao,* Bruce Peebles & Co., Ltd.

CP.* Report on Experience Using AIEE No. 511 for Evaluating Insulating Systems for Rotating Machines. Working Group for AIEE No. 511. G. L. Moses, chairman

Information Processing and Retrieval

CP.* Post Office Mechanization. *B. M. Levin, M. C. Stark, P. C. Tosini,* National Bureau of Standards

CP60-807. Information Storage and Retrieval Part I—Dogs, Cats, and Indexing. *A. F. Glimn, R. D. Greenway,* General Electric Co.

CP60-859. Design Considerations for Computer Driven Displays in the FAA Man-Machine Simulator for the Study of Air-Traffic Control Systems. *R. P. Niquette,* The Thompson-Ramo-Wooldridge Products Co.

60-215. The *LN 3000* Computer Control System. *K. G. Harple, R. G. Lex, Jr.,* Leeds and Northrup Co. (represented for discussion only)

Radio Communication Systems

CP60-792. A New Look at Coastal Radiotelephone Engineering. *C. F. White,* Pacific Telephone Co.

60-793. Providing 150-Mc Telephone Service to North Carolina's Ocracoke Island. *M. B. McMillan,* Carolina Telephone & Telegraph Co.

CP60-794. Practical Narrow-Band System Operation. *T. A. McKee,* General Electric Co.

CP60-795. A Communication System for a Canadian Gas Pipeline. *D. M. Atkinson,* The Bell Telephone Co. of Canada

CP60-892. Merits of Transistorized Mobile Radio Equipment in the Utility Field. *B. W. Conover,* South Jersey Gas Co.

60-899. R. F. Transmission Line Engineering. *R. F. Lewis,* Prodelin, Inc. (represented for discussion only)

New Activities and Research

Panel Discussion on: Exploring the Future of Direct Energy Conversion

Lighting for Land Transportation

CP.* Electrically Operated Railroad Switch Lamps. *H. L. Folley, W. A. Costello,* Western Railroad Supply Co.

CP.* Modern Light Sources for the Railroad Industry. *R. D. Churchill, R. L. Henderson,* General Electric Co.

CP.* Catenary-Mounted Luminaries for Railroad Yard Lighting. *A. W. Herman,* Line Material Industries

Friday, June 24

9:00 a.m. Morning Sessions

Computer Applications in Power Systems

60-225 Digital Calculations of Single-Phase-to-Ground Faults. *H. E. Brown, C. E. Person,* Commonwealth Edison Co. (re-presented for discussion only)

CP60-897. Computer Solution of Transmission Line Intermediate Point Faults with Mutual Coupling. *M. J. Lantz,* Bonneville Power Administration

CP60-845. System Representation, Data Handling, and Interpretive Techniques for Digital Power Flow Studies. *M. A. Schnetzler, J. B. Cage,* Allis-Chalmers Manufacturing Co., *J. J. Skiles,* University of Wisconsin; *E. Jochum,* Commonwealth Edison Co.

60-781. A Digital Method for Obtaining a Loop Connection Matrix. *W. F. Tinney, C. M. McIntyre,* Bonneville Power Administration

60-780. Digital Calculation of Network Inverse and Mesh Transformation Matrices. *N. Sato,* Bonneville Power Administration

Power System Communications

Rotating Machinery

CP60-854. The Parallel Rail Electromagnetic Accelerator. *R. M. Bergslien, J. L. Radnik, A. Bak,* Illinois Institute of Technology

CP60-889. Silicones in Enclosed D-C Machines. *U. M. Elder,* Westinghouse Electric Corp.

CP.* Iron Saturation and Magnetization Characteristic in Electrical Machines. *J. Ben Uri,* Carnegie Institute of Technology

CP.* Generalized School Set. *J. J. Riley,* Westinghouse Electric Corp.

Computing Devices & Semiconductor Metallic Rectifiers

Industrial and Commercial Power Systems

CP60-799. Power Company Policies in Serving Industrial Plants. *D. T. Michael,* The Cincinnati Gas & Electric Co.

CP.* Written Discussion of Mr. Michael's Paper. *J. H. Beckmann,* Philadelphia Electric Co.

CP60-800. Factors Determining Primary Substation Ownership. *C. C. Saunders,* E. I. DuPont de Nemours & Co., Inc.

CP.* Written Discussion of Mr. Saunders' Paper. *R. H. Felch,* Owens-Corning Fiberglas Corp.

2:00 p.m. Afternoon Sessions

System Engineering Problems

60-791. Principles of Economic Dispatching for Electric Power System Operators. *H. B. Smith,* Niagara Mohawk Paper Corp.

CP60-846. Methods of Controlling Generation on Interconnected Power Systems. *N. Cohn,* Leeds & Northrup Co.

60-867. Direct Calculation of Transmission Loss Formula—I. *L. K. Kirchmayer, H. H. Happ,* General Electric Co.; *G. W. Stagg, J. F. Hohenstein,* American Electric Power Service Corp. (re-presented for discussion only)

CP.* A Generalized Form of the Nyquist Diagram and on Illustration of its Application to Electric Power Systems. *S. L. Mikhail,* Ain-Shams University

Rotating Machinery

60-774. Mathematical Analysis of Inductor Alternators. *A. K. Das Gupta,* Illinois Institute of Technology

60-773. Analytical Method To Find the Best Number of Stator and Rotor Teeth of Inductor Alternator for 3-Phase Sinusoidal Voltage Generation. *A. K. Das Gupta,* Illinois Institute of Technology

60-850. Pole-Changing of Salient Pole Synchronous Machines. *K. Sano,* Tokyo Shibaura Electric Co., Ltd.

CP60-851. Performance of a New Static-Magnetic Exciter and Voltage Regulator for Round Rotor Marine Steam Turbine Generators. *D. F. Talcott, P. M. Tabor, C. Concordia,* General Electric Co.

CP60-852. A New Frequency Converter Excitation "FCE" System for A-C Generators. *K. M. Sparrow,* Lima Electric Motor Co.

Semiconductor Metallic Rectifiers

Industrial and Commercial Power Systems

CP.* Testing and Setting of Relays on Industrial Power Systems. *C. E. Batchelder, W. N. Landis,* General Electric Co.

CP.* Nonleaded Cable Terminations. *C. E. Mindnich,* General Electric Co.

60-801. The Case for Standardizing Airport Apron-Outlet Distribution Systems at 1,000-Volts, 400-Cycles. *J. B. Chapman,* Ammann & Whitney

R. E. Stoffels Wins Chicago Section Papers Contest

R. E. Stoffels (AM '53), a member of the technical staff of Automatic Electric Laboratories, Northlake, Ill., has won first place in the Section papers competition of the AIEE Chicago Section.

His paper, entitled " 'Datacom' Unit—An Experimental Data Transmission Subset," concerned the development of equipment for the transmission of digital data over telephone lines.

Mr. Stoffels will present a similar paper in June at the AIEE Summer General Meeting in Atlantic City, N. J. He is also slated to speak at the National Conference on Electromagnetic Relays at Oklahoma State University. The Stillwater, Okla., presentation outlines "A Practical Method for the Prediction of Relay Operate Time."

An electrical engineering graduate of Northwestern University, Mr. Stoffels joined Automatic Electric Laboratories, a subsidiary of General Telephone & Electronics, in 1949 as a co-op student. Since 1952, he has been engaged in research and development work on data transmission systems. He serves on the AIEE Data Communications Committee (1958-60), in the Electrical Industries Association, and is a member of Eta Kappa Nu.

Photos by Clarence Hansen

AIEE members checked in at the Pfister Hotel (above, *left*) for the Great Lakes District Meeting. Shown at the banquet (*center photo, left*) were: (*left to right*) AIEE President and Mrs. J. H. Foote, Jackson, Mich.; Mr. and Mrs. L. S. Van Slyck, Fargo, N. Dak.; and Mr. and Mrs. R. H. Rech, Milwaukee, Wis. Prominent members attending the meeting were: (*photo at left, from left to right*) F. W. Bush, vice-president elect, Great Lakes; H. C. Brem, Milwaukee; S. N. Witts, Minneapolis; J. A. Deubel, Milwaukee; R. B. Gear, vice-president, Great Lakes; and J. H. Foote. Members are pictured at the general session luncheon (*above, right*). The 1960 District Meeting Committee (*below, right*) included the following: (*standing, left to right*) R. H. Rech, banquet; J. Frank, luncheon; D. Pettit, technical program; R. E. Horn, arrangements and hotels; T. Progler, technical program; W. C. Rhine, registration and sales; Harold Whiting, special meetings and inspection trips; John Santi, arrangements; Al Cygal, hotels; Bill McCoy, student activities; E. A. Dickinson, entertainment; H. C. Brem, administration and publicity; and (*seated, left to right*) W. R. Ibach, Milwaukee Section chairman; J. A. Deubel, technical program; L. H. Matthias, technical program; and R. J. Ungrodt, Milwaukee.

Registration of About 650 Noted for Great Lakes District Meeting in April

APPROXIMATELY 650 members and guests were registered for the AIEE Great Lakes District Meeting, held April 27-29, at Milwaukee, Wis. The theme of the meeting was "Controls—Pearl Street to Cape Canaveral." Those attending included a number from Canada.

Seventeen technical sessions were conducted at which 72 papers were presented. Eight inspection trips were arranged to give those members making them an insight into the electrical industry of Milwaukee's environs.

The general session was combined on the opening day of the meeting with a luncheon at which AIEE President J. H. Foote spoke. That evening a typical Milwaukee gemütlichkeit party was enjoyed, followed by dinner and a performance of "Brigadoon" in a theatre-in-the-round.

At the banquet on Thursday evening, W. M. Wallace, vice-president and general manager of the Allis-Chalmers Industrial Equipment Division, was the featured speaker. He said that from research now in progress, a flow of new materials—plastics, ceramics, and metal alloys—will develop which will permit many changes in both consumer and capital goods.

In the consumer field, these new materials will lead to changes in product styling and packaging. In the field of capital goods, the result will be more compact machines and improvements in automatic controls.

R. B. Gear, AIEE vice-president of District 5, announced the winners of the District's student paper competition. First place was awarded to Agosta Spencer, Santiago, Chile, a student at Notre Dame. He won $25 and a trip to the AIEE Summer General Meeting in Atlantic City, N.J., in June. The second prize was awarded to Richard Pawula, Illinois Institute of Technology, and third prize to Michael Henebry, University of Illinois.

Student engineers from 13 colleges competed in the contest.

The ladies' program included a tour of the radio and television studios of WTMJ, luncheons, and a visit to the Milwaukee Art Center.

Luncheon Session

At the general luncheon session, AIEE President J. H. Foote was the featured speaker. He pointed out that only approximately 10% of the total membership of the Institute were really participating in its activities and furthering the work to be done. He urged that other members be spurred out of their complacency and encouraged to work on the many problems of the Institute.

The young engineer, Mr. Foote said, should see how his efforts fit into man's society and engineering work; AIEE can assist him in this. The older engineer, who sits back and does little or nothing, should get his mind into a more active frame of reference and understand how the Institute really is the integrator of electrical engineering matters.

Mr. Foote expressed the hope that other engineering groups, such as the Illuminating Engineering Society and the Instrument Society of America, would some day be one with AIEE, for it is an inclusive type of organization. He spoke of the joint AIEE-IRE (Institute of Radio Engineers) committee, existent for several years, which is working toward the joining of their two engineering memberships. They both have many things in common, and he believes that both societies would benefit from a merger.

Technical Sessions

The 72 papers presented at the meeting in the main dealt with power and control fields, although there were sessions on missiles, guidance, and education.

One of the outstanding papers was given by Capt. R. R. Rath, Air Force Ballistic Missile Division, entitled "Control Systems for Ballistic Missiles: Requirements, Mechanization, and Problems." He discussed the difficulties encountered in locating the control system in a missile, due to the fact that it is so long in relation to its width. A block diagram of one axis of a missile control system was presented in which the gyro controls and the attendant amplifiers were shown and discussed.

The four papers given at the session devoted to electrical engineering education were of great interest and brought about extended discussion. Prof. W. B. Swift of the University of Wisconsin, in his paper "Explosion in Electrical Engineering," showed curves of the past and future growth of the number of students in this field. He estimated that the growth would be about 7% each year.

Prof. J. D. Horgan, Marquette University, presented "Education for 2000 A.D.," in which he told about an unusual curriculum which is geared to the future of the students. One of the sections that caused a great deal of discussion was the "professional art" that is followed by "engineering methods." This is a sequence that is directed to giving the student as much practice as possible in solving real engineering problems.

Another paper which attracted a great deal of attention was "Detection and Control of Aircraft on the Airport Surface" by M. A. Warskow and J. E. Woodward, Airborne Instruments Laboratory Division of Cutler-Hammer, Inc. The author considered a radar system which not only provides manual control of aircraft, but also an automated version of this control which obtains for all weather conditions. This radar system, such as the one installed at Idlewild Airport in New York City, is designed especially for those airports which have runways which cross one another.

South West District Meeting Was Keyed to Industrial Growth

THE AIEE South West District 7 Meeting was held in Houston, Texas, April 4-6, at the Shamrock-Hilton Hotel. The theme of the meeting was "Electricity—Pacemaker of Industrial Growth in the Great Southwest" and the 635 members who attended were presented with great evidence of that fact.

In addition to the 20 technical sessions, the meeting included a luncheon, a theatrical review, a banquet with a social hour preceding it, and the general session. Three inspection trips to leading industries were held as well as a sightseeing trip through the Houston Ship Canal on the *MV Sam Houston*. The program for the ladies included a fashion show, luncheons, and a visit to the new Houston Enginering and Scientific Building.

Two New Districts Formed

Vice-President I. T. Monseth of District 7 opened the general session, stress-

THERMOELECTRICITY was the subject of an address by Dr. J. H. Hutcheson, vice-president of Westinghouse Electric Corporation, at the South West District Meeting.

AT the general session of the South West District Meeting, AIEE President J. H. Foote (left) spoke of the Institute's intention to make the Board of Directors even more fully representative of technical interests than hitherto. Beside him was N. F. Rode, an AIEE director and electrical engineering professor of the A&M College of Texas.

ing the fact that this was the final meeting of District 7 which would now be known as the Mid America District and that District 15 would be the new South West District, effective August 1960.

Mr. Monseth then introduced the general chairman of the meeting, P. H. Robinson, who in turn introduced Houston's Mayor L. W. Cutrer. He welcomed the members to the city and told briefly what a great role engineers have played in the development of Houston.

AIEE President J. H. Foote was then introduced. After telling about the new United Engineering Center now under construction and the part that District 7 has played was in the fund raising, he explained the proposed changes in the Institute's constitution, which were intended to make the Board of Directors even more representative of Institute technical interests. He stressed that there must be an improved relationship between science and engineering.

Thermoelectricity Described

Dr. J. A. Hutcheson, vice-president, Westinghouse Electric Corporation, the next speaker, gave an excellent address on the new means of generating power: thermoelectricity. He stated that new prime sources will become necessary in the not too distant future because many factors are deleting our conventional fuels.

Dr. Hutcheson said that fuel cells, thermoelectricity, thermionic generators, and magnetohydrodynamics are really not new, as their principles were studied in the 19th century. We have only begun to understand their principles recently. He demonstrated what high temperatures were needed to generate power of sufficient magnitude and spoke about the comparative sizes of the power plants. He stated that all the techniques he had explained have great potentials in the generation of power and that they doubtless would reduce the cost of power and capital costs and that these new concepts would increase the efficiency of plants.

Politics for Engineers

At the luncheon meeting, which followed the general session, H. S. Skinner of the Continental Oil Company gave a talk entitled, "A Political Speech—1960." He said that the 2-party system not only provides the manpower for government, but also provides the flow of ideas and convictions that animate government. He urged that the engineers who are affiliated with utilities voice their opinions now and not when it is too late.

At the banquet, at which P. H. Robinson presided, the Lamar Mixed Chorus gave an excellent concert, which was followed by an address by D. S. Kennedy, Oklahoma Gas and Electric Company. The speaker compared the power generating facilities of the United States and Russia, showing that at the end of 1959, the difference was 124 million kw in our favor, and he predicted that by 1965 this difference will have widened to about 134 million kw, with the United States still in the lead.

Mr. Kennedy brought out the fact that in steam, hydro, and nuclear power generation as well as in transmission facilities, we are ahead of the Soviets. He also said that more women were employed around Russian power plants than we are used to seeing here—in fact, many more women are employed in the electrical industries behind the Iron Curtain than in this country. He concluded that the Russians will not catch up with us in the production of electric power at any time in the foreseeable future.

The subjects covered by the 20 technical sessions varied from power system engineering to communication in space and from chemical and petrochemical engineering to power substations and relaying.

AIEE Joint District Meeting Held in April at Charleston, W. Va.

ABOUT 225 engineers, students, and guests participated in the East Central and Allegheny-Ohio Valley District Meeting on April 11-14, 1960, in Charleston, W. Va., at the Daniel Boone Hotel.

In addition to the technical sessions, there were various social activities: a banquet on the evening of April 13, at which P. H. Miller, Jr., General Dynamics Corporation, spoke on "From the Atom to Your Home—Electric Power Generation Without Moving Parts," an informal "Guys and Gals Party," and inspection trips and sightseeing tours for the ladies.

Inspection trips of technical interest were made to the following industrial plants and sites: Union Carbide Technical Center, South Charleston, W. Va.; Kanawha Power Plant, Glasgow, W. Va.; Coal Preparation Plant, Cannelton Coal & Coke Company, Cannelton, W. Va.; and the Owens-Illinois Glass Company, Charleston.

The West Virginia Institute of Technology sponsored a student prize paper competition with a cash award of $25 and an expense-free trip to the forthcoming Summer General Meeting as the first prize, $25 to the second prize winner, and $15 as the third prize. Winners were: first prize—O. A. Kolody and G. A. Praver, Case Institute of Technology, for their paper "Marine Navigation Control System"; second prize—W. A. Lippold, West Virginia University, for his paper "Electrets"; and third prize—Pat Klosky and Charles Bulick, Fenn College, for their paper "Arc Suppression and Application."

Benton Studio

CONTESTANTS in the student prize paper contest sponsored by the West Virginia Institute of Technology at the East Central and Allegheny-Ohio Valley District Meeting were winners of competitions at their Student Branches. Shown are: *(left to right, seated)* Pat Klosky, Fenn College; Thomas Sweitzer, Akron University; D. C. Jessup, Jr., University of Pittsburgh; W. A. Lippold, West Virginia University; Roman Skuljins, Jr., West Virginia Institute of Technology; *(standing)* Prof. P. M. Gray, counselor at the host school; R. A. Elco, Carnegie Institute of Technology; O. A. Kolody, Case Institute of Technology; G. A. Praver, Case Institute of Technology; Charles Bulick, Fenn College; Prof. R. C. Gorham, University of Pittsburgh, Student Activities Committee chairman of the Allegheny-Ohio District.

General Session

Mayor J. A. Shanklin of Charleston and Governor C. H. Underwood of West Virginia extended their appreciation and welcome to the delegates assembled in the Shrine Mosque Auditorium.

R. E. Salvati, president, Island Creek Coal Company, delivered the keynote ad-

dress on "Fuels for the Future." He foresaw within the next 10 to 15 years, an annual demand for bituminous coal of 600 to 700 million tons. The cost of expanding capacity to meet this demand would run to billions of dollars. Mr. Salvati urged all consumers and especially the electric utilities to join the coal industry in seeking solutions to this problem that will accrue to the benefit of all concerned.

C. B. Talley, Appalachian Power Company, was chairman of the General Session.

AIEE President J. H. Foote spoke at the luncheon which followed the general session. He stressed the urgency of Institute members' keeping up with developments in the engineering field where the rate of discovery in all sectors is constantly increasing. One way to do this is through increased committee activities and, where necessary, splitting committees to form new ones embracing a sector of activity that has become too large and complex to handle. This will help avoid the development of splinter groups. Basic to the problem of revitalizing the Institute, however, is the need to permeate the organization with something akin to Thomas A. Edison's spirit and inventive mind which enabled Edison to more than keep abreast of his times.

Benton Studio

PARTICIPATING in the Space Problems Symposium at the East Central and Allegheny-Ohio Valley District Meeting were: (*left to right*) Dwight Thompson, Minneapolis-Honeywell; J. L. Simpson, session chairman; Sidney Krasik, Westinghouse Electric Corporation; Mark Ghai, General Electric Company; and F. D. Drake, National Radio Astronomy Observatory.

Technical Sessions

Cathodic Protection and Grounding. The effect of electrical grounding systems on underground corrosion and cathodic protection was discussed by B. Husock, Harco Corporation. The increased use of electricity necessitates the use of more extensive grounding systems in industrial and power plants by means of made grounds employing copper. The serious corrosion effects on the underground structures of iron or steel and the way to mitigate these effects were discussed at length. Papers on the topics of underground corrosion, on rural electric distribution lines, and on grounding and bonding were also presented. At a later session, W. J. Kretschmer, Columbia Gas System Service Corporation, read a paper on "Demonstration of the Theory of Cathodic Protection."

Fire Prevention in Industry. A. D. Colburn, Union Carbide Chemicals Company, discussed static and induced current grounding. He pointed out sources of static in industry and what can be done to try and eliminate static build-up. A paper on safe instrumentation in a chemical plant stressed the spreading electrical and nucleonic hazards resulting from increased use of instrumentation. The subject mattter was, however, restricted to electrical hazards, and several avenues for circumventing electrical hazards were explored.

Chemical Industry. Two sessions were devoted to this topic. The first session explored the area of instrumentation and data transmission—analytical instruments for process control, data transmission capabilities of the telephone network, and the data-phone as a linkage in process control systems. The second session covered computation and control problems in this industry. One paper presented analog computer models for process control; another discussed the role of the general purpose computer in plant maintenance. The latter paper covered the use of a punched card record system and a general purpose computer to keep track of instrument investment, record and study maintenance performance, and to schedule preventive maintenance. In addition, a digital computer for process control was the subject of a paper by K. R. Knoblauch, Minneapolis-Honeywell.

Mining Industry. Pushbutton coal mining has taken another step toward realization with the introduction of the Joy Pushbutton Coal Miner, a machine weighing approximately 1.2 million pounds. The design and operation of the machine was explained by K. L. Shrider, Joy Manufacturing Company. J. W. Heimaster discussed remote control highwall mining, and D. E. Hamilton presented a review of mine electrical grounding practices. Other papers were on fuel cells, portable silicon rectifiers for mining service, and on electric equipment for coal cleaning plants.

Engineering Education. A description of a communications engineering course to meet the challenge of a fast moving technology was given by C. T. Koerner, American Telephone and Telegraph Company. The attempt is being made to provide a solid foundation of the engineering sciences most closely related to electrical communication in the telephone operating companies of the Bell System. The speed of acceptance and effective utilization of new instrumentalities depends in significant measure on the success of such programs. There were also papers on the evolution of electronic components, an experiment in laboratory education, and "A Program in Engineering Science," by A. T. Murphy, which appeared in *Electrical Engineering*, October 1959.

Industrial Power. This session heard papers on the following topics: the electrical testing of rubber and plastic insulated power cables, the digital computer in industrial power system design, relay protection for large motors, and static protective relays. There were also papers on the Plasmarc Torch, and "Selecting an X-Ray Gauge for Measuring the Thickness of Aluminum Foil."

The last session on Thursday afternoon was devoted to a Space Problems Symposium. The area of discussion covered radio astronomy, space instrumentation and guidance, application of nuclear power to space problems, and space motors and propellants. Taking part were F. D. Drake, National Radio Astronomy Observatory; Roy Crask, Minneapolis-Honeywell; Sidney Krasik, Westinghouse Electric Corporation; and Mark Ghai, General Electric Company.

Drexel Institute Is Host to District 2 Paper Contest

Nine first place winners from District 2 Student Branches met at Drexel Institute April 29 for the annual district prize paper contest. The conference was opened by Drexel Branch Counselor F. C. Powell who introduced Dr. L. A. Brothers, dean of engineering, for keynote remarks on the importance of prize paper participation.

Conference activities concluded with a banquet presided over by Prof. Powell. A discussion of the strong and weak points of the papers presented during the day was given by two of the contest judges E. R. Scattergood of Philadelphia Electric Company and Dr. L. E. Mertens, Radio Corporation of America, Camden, N.J.

Prof. H. M. Chandler, Jr., Princeton University Student Activities Committee chairman, presented the prize awards to:

First Place—A. Graps, Jr., George Washington University, for his paper, "Signal Flow Graphs."

Second Place—H. S. Stone, Princeton University, for his "Minimization of Hazard-Free Switching Networks."

Third Place—R. B. Swerdlow, University of Pennsylvania, for the paper, "A Rotary Power Amplifier."

District Vice-President D. L. Greene presented a trophy for the first place winner and another for his school.

Wear Your ◆ AIEE Badge

General Electric Company

DISPLAYED at the Nuclear Congress was Allis-Chalmers Manufacturing Company's animated scale model of the first nuclear power plant designed to include a reactor with integral nuclear superheater, the Pathfinder station (photo at left). The 66-mw (electric) plant for Northern States Power Company will be built at Sioux Falls, S. Dak. Another exhibit (photo at right) was this scale model of a radiation measurement trailer, designed and built for the Atomic Energy Commission by the General Electric Aircraft Nuclear Propulsion Department for improving the means for gathering extremely accurate information on radiation sources. The trailer is used for measuring radiation distribution from sources ranging from huge power reactors to small industrial X-ray machines.

Role of Nuclear Engineering Discussed at 1960 Nuclear Congress

THE 1960 Nuclear Congress, an important event of common interest to virtually all engineers, was held at the Coliseum in New York City on April 4-8. The week-long meeting was sponsored by 28 engineering and scientific organizations, including the AIEE, and co-ordinated by the Engineers Joint Council. As in the past, the International Atomic Exposition was held in conjunction with the Congress.

At the All-Congress Session, held Monday morning, the theme was "What Will Future Development of Nuclear Energy Demand from Engineers?"

John Simpson, Westinghouse Electric Corporation, discussed the role of the nuclear engineer in outer space exploration. He predicted that by 1970 the United States will be able to orbit a nuclear-powered electric generating system with a capacity of 60,000 kw.

The problem of fuel utilization in future atomic power plants was the subject of a paper by W. H. Zinn, Combustion Engineering, Inc.

W. K. Davis, Bechtel Corporation, discussed some of the engineering requirements to be expected for future nuclear applications.

The session closed with a paper entitled "Frontiers Require Fundamentals," by Gale Young of the Nuclear Development Corporation of America. He stressed the importance of "rolling back" the use of fossil organics as mere fuels, in order to preserve them for more valuable purposes. He declared that atomic energy and solar energy would be partners in accomplishing this task.

A total of 62 papers, covering seven major areas of interest in the atomic field, were presented. They were carefully selected to deal with nuclear problems which the program committee, headed by E. B. Gunyou, felt needed more clarification and study. These papers were selected and invited so as to avoid duplication of any presented at other atomic conferences. The seven areas of interest covered were as follows: reactor construction, reactor design, environment, materials and components, nuclear standards, isotopes, and radiation processing.

Also co-ordinated with the Congress program was a group of three sessions sponsored by the Society of Automotive Engineers (SAE) and held Wednesday evening and all day Thursday at the Hotel Commodore. Nine papers were presented on nuclear-propelled space vehicles and their components.

A special feature of the Congress was a seminar on the industrial uses of radioisotopes, which was held Wednesday afternoon and all day Thursday at the Coliseum under the sponsorship of the National Association of Manufacturers and agencies of the States of New York, New Jersey, Pennsylvania, and Delaware, in co-operation with the U. S. Atomic Energy Commission, Office of Isotopes Development. The purpose of this program was to broaden and improve management's knowledge of atomic energy as an industrial tool and instrument.

Exposition Described

More than 150 atomic exhibits from Canada, Switzerland, France, and the United States were on display at the 6th International Atomic Exposition, held in the Coliseum. The exposition featured the latest equipment, products, and services available to the nuclear industry and covered the fields of nuclear design, construction, manufacturing, and components.

Among the exhibits were a specially designed filter made by the Cambridge Filter Corporation, Syracuse, N. Y., that is capable of removing even the minutest radioactive dust particles from the air. It was designed to remove radioactive particles in the air exhaust from "hot" or radioactive laboratories, power reactor vessels, caves, and research reactors.

Two unusual electronic devices—one a reactor simulator, the other a thermal simulator that realistically acts like a full-scale atomic power plant—were exhibited by Minneapolis-Honeywell Regulator Company. The reactor simulator recreates electronically the operating characteristics of actual reactors using fissionable fuels. It is being used by a number of universities as a training device. The thermal simulator, when linked to the reactor simulator, duplicates the reactions and effects of any kind of atomic power plant except that of a boiling water reactor. It also can be used to solve nuclear design and operational problems.

A "do-it-yourself" kit of the Pulsatron, a small-size and lightweight portable neutron generator, was shown by Kaman Nuclear, Colorado Springs, Colo. The kit was designed primarily for universities desiring inexpensive sources of neutrons for classroom experiments in nuclear physics. It will permit a group of students to build a neutron generator in their own laboratory.

A working "live" demonstration of the Mobot Mark IB, a remotely controlled handling robot with flexible steel hands and television-camera eyes, was a feature of a Hughes Aircraft Company exhibit. The Mobot can be applied to almost any situation which is too dangerous for man to undertake himself. Radio-controlled, it can work in highly radioactive areas and handle materials in deep water. Hughes scientists foresee Mobots that can plant and harvest crops in the sea, fight forest and other big fires from within the blaze, perform mining operations, and rescue men from disaster areas such as those filled with poisonous gases.

A model of the world's largest privately owned facility for remote examination of radioactive materials was exhibited by Atomics International. Critical experi-

ments laboratories, six nuclear reactors and support equipment will be shown in the model of the company's 290-acre nuclear field laboratory located in the Santa Susana Mountains near Los Angeles, Calif.

Technical Papers Available

For those who found it impossible to attend the 1960 Nuclear Congress, and to obtain printed copies of papers at the Congress, provision has been made for mail order distribution. This facility has been provided as part of the first objective of the Congress, "to provide free exchange of knowledge in the subject areas between engineers and scientists and the industry which is dependent upon such information."

Each paper in the following list carries a number. These papers may be ordered by number, or the complete set may be obtained. The price is 50¢ per paper, or $20 for the set. Address all orders to the 1960 Nuclear Congress, 29 W. 39th St., New York 18, N. Y.

6. Experience in Use of Organic Coolant in Nuclear Reactors. *S. C. Spencer, W. N. Bley, R. W. Burkhardt, G. O. Haroldsen,* Atomics International
7. Low Impurity Core Materials. *D. D. Foley, G. P. Pancer, J. L. Zegger,* Alco Products, Inc.
8. Bureau of Mines Research on the Fused Salt Electrorefining of Beryllium. *D. H. Baker, Jr., M. M. Wong, R. E. Campbell,* Boulder City, Nev.
9. Preparation of High Purity Thorium by Reduction with Sodium. *F. E. Block, P. C. Good,* U. S. Bureau of Mines
10. Results of 1959 Nuclear Power Plant Containment Tests. *Alf Kolflat,* Sargent and Lundy
11. Review of Shippingport Operations—Site Factors. *J. E. Gray,* Duquesne Light Co.
13. Civil Engineering Aspects of Nuclear Power Plants. *R. W. Kupp, J. C. Tourek,* Vitro Engineering Co.
14. Sites for Nuclear Power Plants for Large Spanish Utility. *Jamie Mac-Veigh,* Tecnatom
15. The Army Nuclear Power Program. *D. G. Williams,* Army Nuclear Power Program
16. BuDocks Role in the Development of Nuclear Power for the Navy's Shore Bases. *W. J. Christensen,* Atomic Energy and Applied Science Branch, BuDocks, Dept. of the Navy
18. Comparative Study of the Natural Uranium Graphite Moderated Gas Cooled Reactors (U.S., British, French, etc.) *Robert Gibrat,* Indatom
19. Status of Regulation at the Municipal Level (Protecting Public Health). *Hanson Blatz,* New York City Health Dept.
21. Status of Regulation on Federal Level: Responsibilities of the U. S. Public Health Service. *F. J. Weber,* Division of Radiological Health, Dept. of Health, Education, and Welfare
22. Current Status of International Regulatory Activities in the Field of Public Health as Related to Atomic Energy and Its Uses in Industry. *A. I. Galagan,* International Atomic Energy Administration, United Nations
23. Ignition and Detonation of Uranium in Promine Trifluoride Solutions. *R. Johnson, F. Horn, G. Strickland,* Brookhaven National Labs.
25. Liquid—Liquid Extraction—Influence of the Physical Properties Variation of Solution Upon Pulsed Column Performance. *Xavier Talmont,* Plutonium Dept., Commissariat à L'Energi Atomique, *Jean Durandel,* French Petroleum Inst.
26. Status of the Plutonium Re-Cycle Reactor. *R. E. Dunn,* Hanford Atomics Products Operation, General Electric Co.
27. Operation and Experimental Use of Battelle Research Reactor. *A. M. Plummer, J. N. Anno, J. W. Chastain, Jr.,* Battelle Memorial Inst.
28. Operating Experience with In-Pile Loops at Oak Ridge National Laboratory (ORNL). *J. A. Cox,* ORNL
29. Construction and Operation of the McMaster Nuclear Reactor. *W. H. Fleming,* McMaster Univ.
30. Design of a Hot Laboratory for Metallurgical Research in Germany. *W. Stephan,* GFKF Inst. Fur Rector—Werkstoffe, Aachen, Germany
31. Applications of Swimming Pool Reactors. *Mrs. J. Libert,* Indatom
32. Basic Requirements of Instrumentation and Control for Closed-Cycle Water Nuclear Power Plants. *C. F. Obermesser,* Westinghouse Electric Corp.
61. Trends in the Control of Reactors in France. *Jacky Weill,* Reactor Electronics Section, *Paul Desneiges,* Applied Electronics Section, Commissariat à L'Energi Atomique
33. Control and Instrumentation Equipment In-Core. *H. M. Ogle, J. Forster, H. H. Hendon, J. H. Keeler,* Atomic Power Equipment Dept., General Electric Co.
35. Present Needs in Instrumentation and Control Technology for Nuclear Power Reactors. *F. C. Legler,* U. S. Atomic Energy Commission Division of Reactor Development
37. Strontium 90 in Surface Water. *C. P. Straub, L. R. Setter, P. F. Hallbach, A. S. Goldin,* Dept. of Health, Education and Welfare, R. A. Taft Sanitary Engineering Center
38. Continuous Calcination of Aqueous Radio-Active Waste Solutions by Radiant Heat. *R. T. Allemann, P. M. Johnson,* General Electric Company
39. Surveillance of a Municipal Water System to Assure Control of Radioisotopes—A Study of the Hanford Atomic Products Operation. *R. L. Junkins,* Hanford Atomics Operation, Richland, Wash.
62. Nuclear Standards—American Society of Testing Materials. *G. D. Calkins,* Atomics International, North American
41. American Society of Mechanical Engineers Committee on Nuclear Power of the Boiler and Pressure Vessel—Nuclear Standards. *D. A. Rogers,* Allied Chemical and Dye Corp.
42. Nuclear Standards—American Standards Association's Materials Task Force, Nuclear Advisory Committee. *J. A. Klapper,* Ebasco Services, Inc.
43. Advanced Water Reactors Systems. *W. E. Shoupp, J. H. Wright,* Atomic Power Dept., Westinghouse Electric Corp.
44. Army Gas Cooled Reactors. *M. A. Rosen, G. A. Bicher,* Division of Reactor Development, U. S. Atomic Energy Commission
45. High Temperature, Gas Cooled, Graphite-Moderated Reactor (HTGR). *David Rose,* John J. Hopkins Lab., General Dynamics Corp.
46. Nuclear Superheaters for Boiling Water Reactors. *E. L. Zebroski, K. M. Horst, P. G. Aline,* Atomic Power Equipment Dept., General Electric Co.
47. Industrial Radioisotope Applications Development Sponsored by U. S. Atomic Energy Commission (AEC). *P. G. Aebersold,* Office of Isotopes Development, AEC
48. Applications of Nuclear Science in the Producing Branch of the Petroleum Industry. *Milton Williams,* Humble Oil and Refining Co.
49. Field Techniques and Instrumentation for Radioactive Gas Tracers. *F. E. Armstrong,* U. S. Bureau of Mines
50. Isotope Power. *J. G. Morse,* Isotopic Power Dept., The Martin Co.
51. Low-Level Tritium Measurement with the Liquid Scintillation Spectrometer. *W. J. Kaufman, Richard Hours,* Univ. of California
52. Progress and Problems in Radiation Processing of Foods. *Walter Urbain,* Swift & Co.
53. Commercialization Technology and Economics in Radiation Processing. *H. F. Kraybill, D. C. Brunton,* Curtiss-Wright Corp., Princeton Div.
54. Radiation Technology for Nonbiological Materials. *A. J. Restaino,* Atlas Powder Co., Industrial Reactor Lab.
55. Current Aspects of the Wholesomeness of Irradiated Foods. *Merrill Read,* Virginia Polytechnic Inst.
56. Determination of Pressure in a 2-Phase Water System. *W. H. Comtois,* Combustion Engineering Inc.
57. Hydraulic Instability of Reactor Parallel Plate Fuel Assemblies. *E. B. Johansson,* Knolls Atomic Power Lab.
58. Natural Convection Flow in Liquid Metal Mobile Fuel Nuclear Reactors. *F. G. Hammitt, E. M. Brower,* Univ. of Michigan
59. A Method for the Economic Comparison of the Th-U-235 Fuel Cycle Versus the U-238-U-235 Fuel Cycle with Application to the MGCR. *R. T. Shanstrom,* General Atomic

Nuclear Congress Scheduled for June 1962 in New York City

The next national Nuclear Congress will be held in New York in 1962, according to an announcement made by Engineers Joint Council (EJC), sponsoring organization of the Congress. This decision by the Board of Directors of EJC was made public by Dr. A. B. Kinzel, EJC's president.

According to Dr. Kinzel, the change in policy of holding annual Congresses, which has been the schedule since its inception in December 1955, to meetings on alternate years "reflects the current needs and interests of the engineering and scientific professions and the nuclear industry."

Dr. L. M. Currie, a pioneer in the nuclear energy industry and chairman of the EJC Nuclear Congress Committee, said, in connection with EJC's announcement of the policy change: "Because of the present pace of development of nuclear technology, our Nuclear Congress Committee felt that it was in the best interests of the industry and its personnel and other participating organizations to have major international meetings and exhibits only once in 2 years. The basic purpose of the Congress with exhibits is to provide a means for all those in the nuclear energy field to exchange ideas and to review the latest innovations in the actual 'hardware' developed. Engineers Joint Council is confident that more fresh material will be available after a 2-year interim. It also hopes that such an interval will insure more efficient preparation of vital new information and, at the same time, make its exchange more profitable."

"It is to be hoped that other engineering and scientific organizations interested in the nuclear field will also help to minimize demands on those directly connected with the nuclear industry," stated Dr. Currie. "This can be done by cutting down on the number and frequency of their own nuclear-oriented meetings and by joining with EJC in a major biennial meeting to serve the engineering and scientific communities as well as the nuclear industry."

The Nuclear Congress was first held in 1955 in Cleveland, Ohio, then in 1957 in Philadelphia, Pa., in 1958 in Chicago, Ill., in 1959 again in Philadelphia, and in New York, this April. As many as 30 national engineering and scientific societies have co-operated with EJC in sponsoring the event, which also has included an international nuclear exposition, displaying everything from table model reactors to full size working reactors. Government and education is represented in the Nuclear Congress as well as industry.

The 1962 Congress is being planned for the first week in June 1962 and will include technical sessions and industry exhibits.

Membership in the American Institute of Electrical Engineers, including a subscription to this publication, is open to most electrical engineers. Complete information as to the membership grade, qualifications, and fees may be obtained from Mr. N. S. Hibshman, Secretary, 33 West 39th Street, New York 18, N.Y.

Inspection Trips Scheduled

AIEE members engaged in atomic power work and nuclear research activities will be interested in the inspection tour to General Dynamics Corporation's General Atomic Division during the 1960 Pacific General Meeting, August 9-12, in San Diego, Calif. General Atomic carries out the corporation's research, development, and production in the field of nuclear science. Metallurgical tests and examinations of radioactive materials are made in General Atomic's "Hot Cell" facility *(left)*. Walls, 42 inches thick, shield the research staff assistants from harmful effects of radiation while they conduct their examinations. Another inspection trip planned for this meeting will be to General Dynamics' John Jay Hopkins Laboratory for Pure and Applied Science *(below)*, situated on the crest of a 300-acre mesa top in northern San Diego. The laboratory provides more than 350,000 square feet for research and development activities.

Management Conference To Take Place September 15-16

Through the co-operation of seven professional engineering societies, the 8th Annual Engineering Management Conference is being planned for September 15-16, 1960, at the Morrison Hotel in Chicago, Ill. The subject of the conference will be "Managing Tomorrow." More than 600 persons are expected to attend the conference.

The conference will be divided into four parts. On the morning of the first day, the "Impinging Forces" will be discussed. This will set the stage for the 2-day conference by identifying the major forces or influences already bearing upon, or beginning to bear upon, (1) the national welfare, (2) private industry, (3) the availability of raw materials, and (4) resources and technology with which to meet national and industrial needs, all to be interpreted in the end for the benefit of engineering management at all levels. Economic forces include consideration of both domestic and foreign competition, availability and cost of raw materials and labor here and abroad, the effect of foreign trade alliances such as the European common market and tariffs.

Some questions to be considered are: Can we maintain a high cost economy when the traditional barriers of distance, inadequate foreign technology, and foreign labor costs are rapidly disappearing. How can this nation properly provide for the technological progress it must make if it is to survive?

"New Requirements and New Aids for Managers" will be the subject of the second session. This is designed to bring out new demands on managers in terms of forecasting, planning, scheduling, organizing, integrating, and measuring technical work and also major advances in using data processing machines to study alternatives and support managerial judgment.

The third session will be concerned with the "Impact on Professional People. This will bring out the continuing trends towards more brain work and less muscle work by men, more repetitive work by machines and less by men, and longer range and more detailed planning, scheduling, integration, and measuring required by the increasing complexity, inner-related effects, and economic impacts of mechanization and automatic machine production.

The "Impact on Education" will be discussed in the final session. This should contain implications for all engineers who are in or aspire to positions as managers of technical work. This will include the impacts on technical schools, business schools, and also on continued postgraduate and home study.

Also on the program is a luncheon address by Walker Cisler, president of the Detroit Edison Company and president of the Power Reactor Development Company. In addition, P. F. Drucker, professor of management, New York University, and author of several books will give the banquet address the evening of September 15.

The seven professional engineering societies sponsoring this conference are: the AIEE, the American Institute of Chemical Engineers, the American Institute of Industrial Engineers, the American Institute of Mining, Metallurgical, and Petroleum Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the Institute of Radio Engineers.

AIEE-ASME To Hold 1960 National Power Conference

The 1960 National Power Conference will be held in Philadelphia, Pa., September 21-23. This is a joint presentation by the Power Divisions of both the AIEE and the American Society of Mechanical Engineers (ASME). An interesting program of local events has been prepared by the local chapters of both organizations.

The conference headquarters will be at the Bellevue Stratford Hotel. All technical sessions and other events will be held at the Bellevue Stratford, except for some of the ladies activities.

The registration department will be open during the afternoon and evening of Tuesday, September 20, and those arriving early are invited to attend the Early Bird Reception.

The accompanying brief outline of the technical program indicates a full schedule with two technical sessions on Wednesday and a panel discussion Wednesday evening.

On Thursday, there will be two technical sessions, one in the morning and one in the afternoon. In the evening, a banquet will be held in the ballroom of the Bellevue Stratford Hotel.

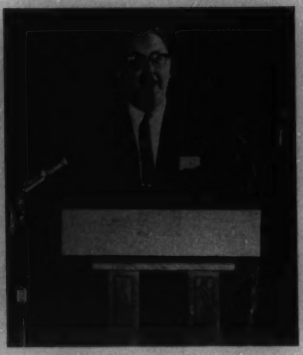
The technical sessions on Friday will terminate at noon, and inspection trips to local plants will be held on Friday afternoon.

The tentative technical program in condensed form, follows:

Wednesday, September 21

Morning Session

Co-ordination of Generation & Transmission & Operation. Three papers will be presented by members of public utilities and manufacturers.



ADDRESSING the first Michigan Section conference meeting were: R. A. Morgan (above) after-dinner speaker; and (photo at left, from left to right) J. A. Nelson, Henry Pantek, D. D. McLeod, B. H. Schneider who is chairman of the section, and R. S. Cataldo.

Afternoon Session

Service Requirements for Industrial Customers. Four papers will be presented by authors from consulting engineering firms, industrial firms, and public utilities.

Evening Session

Advancement of Power Engineering. This will be a panel discussion by men from utilities, industry, and educational institutions.

Thursday, September 22

Morning Session

Power Plant Automation. Four papers will be presented by persons from the public utility field and from the manufacturing field.

Afternoon Session

Power Plant Automation. This will be a continuation of the morning session. Four additional papers by men from the control industry will be presented.

Friday, September 23

Morning Session

Advancements in Economic Power Production. The four papers presented here will be prepared by members of the boiler and turbine industry and of the public utility industry.

Inspection trips are planned for the Eddystone Station of the Philadelphia Electric Company, for the Westinghouse Electric Corporation Steam Turbine Plant, and for the General Electric Company's Switchgear Plant. The buses will leave for the various plants from the Bellevue Stratford Hotel and will return to the hotel at the termination of the visits. All three of these plants are located in relatively close proximity to the Philadelphia Airport, and arrangements can be made for the returning buses to stop at the airport for those visitors who desire this service.

Visitors who wish to look over some other interesting plants in the Philadelphia area may make special arrangements for additional tours.

The auxiliaries of both engineering societies have prepared an interesting program for the visiting ladies. The ladies' program includes visits to points of historical interest and luncheons.

Michigan Section Holds Initial Conference Meeting

The first Michigan Section conference meeting of the AIEE was held on Tuesday, March 8, at the New Wolverine Hotel, Detroit, Mich.

Events began with cocktails at 5:15 p.m., followed by dinner in the Grand Terrace ballroom.

The after-dinner speaker, R. A. Morgan, advertising and sales promotion manager of Westinghouse Electric Corporation, discussed "Advertising to Engineers."

The conference program consisted of four technical group meetings. The group topics and speakers were:

Communications Group.

The Transatlantic Cable. *D. D. McLeod*, senior engineer, Michigan Bell Telephone Co.

Industry Group.

Automatic Control Guidance of the Firebird III. *R. S. Cataldo*, senior research engineer, General Motors Research Labs.

Power Group.

Higher Voltages for Residential Customers. *J. A. Nelson*, electrical engineer, Commonwealth Associates, Inc.

Science and Electronics Group.

Medical Electronics. *Henry Pantek*, instructor of surgery, University of Michigan Medical School.

Conference Papers Open for Discussion

Conference papers listed below have been accepted by AIEE *Transactions* and are now open for written discussion until June 27. Duplicate double-spaced typewritten copies of each discussion should be sent to E. C. Day, Assistant Secretary for Technical Papers, AIEE, 33 W. 39th St., New York 18, N. Y., on or before June 27.

57-714 **Adjustable-Frequency Drives with Rotating Machine Power Supply.** *A. T. Bacheler, C. G. Helmick*

60-43 **The REA-1 Transposition System.** *A. G. Chapman, J. V. Buscemi, J. M. Flanigan*

60-75 **A New Ceramic Triode for VHF Applications.** *J. D. Campbell*

60-119 **A Generalized Chemical Processing Model for the Investigation of Computer Control.** *J. Williams, R. E. Otto*

60-159 **A New Control Terminal for Mobile Telephone Service.** *L. E. Getgen, Greg McGibbon*

60-215 **The LN 3000 Computer Control System.** *K. G. Harple, R. G. Lex, Jr.*

Preprints may be purchased at 50¢ each to members, $1.00 to nonmembers, if accompanied by remittance or coupons. Please order by number and send remittance to: AIEE Order Department, 33 W. 39th St., New York 18, N. Y.

Prize Paper Winners

HONORS in the Cleveland Section Prize Paper Competition went to *(left to right)*: R. C. Thomas, Square D Company, second place winner with "Design of 110-kv Impulse Generator for Laboratory Use," and B. H. Baldridge, Bailey Meter Company, first place winner for his paper "A Control System for a Fast Breeder Nuclear Reactor." Tied for third place were: R. R. Secunde, Jack & Heintz Company, for "Semiconductor Magnetic Overvoltage and Underfrequency Protection Circuits," and H. E. Strong, Ohio Bell Telephone Company, for "Automation Applied to Mobile Radio and Transmission Surveys." The competition was held March 17 at the Cleveland Engineering Societies Building, Cleveland, Ohio.

Goodyear Aircraft Toured

Goodyear Aircraft Corporation

AKRON, OHIO, Section members visited the Goodyear Aircraft Corporation in Akron on February 9. In this photo, taken in the Wheel and Brake Laboratory of the corporation, are: *(left to right)* F. W. Nimmer, Ohio Edison Company; D. C. Emery, Allis-Chalmers Company, and Akron Section chairman; E. F. Huston, Ohio Brass Company, and Akron Section vice-chairman; and L. J. Turner, Goodyear Aircraft Corporation. Approximately 35 engineers employed by Goodyear Aircraft are members of the Akron Section.

First Annual JACC Will Be Held September 7-9

The first annual Joint Automatic Control Conference (JACC) will take place September 7-9 on the campus of the Massachusetts Institute of Technology (MIT).

The objective of the JACC is to establish a single high-level technical conference devoted exclusively to the theory and application of automatic control techniques and equipment. This unique venture recognizes the growing stature and importance of the field of instrumentation and control within the broader interests of the five co-operating societies.

The JACC sponsors are the AIEE, the American Society of Mechanical Engineers (ASME), the American Institute of Chemical Engineers (AIChE), the Institute of Radio Engineers (IRE), and the Instrument Society of America (ISA). ASME is the host society for 1960.

The program will total 18 technical sessions, with three sessions going on simultaneously during the six morning and afternoon periods. The program committee will integrate papers and schedule their presentation according to subjects of prime interest to conference attendees. Among the 18 sessions will be three sessions on sampled data and adaptive control, three on process dynamics, four on computer control, and three on control components.

A special feature will be a first-hand report on the proceedings of the first International Congress of the International Federation of Automatic Control to be held in Moscow, USSR, this June. This report will be given on the Thursday evening of the JACC conclave.

Accommodations for 250 attendees and their wives will be available on the MIT campus. Further information and a copy of the advance program to be ready this Summer may be obtained from the JACC general chairman, W. D. Archibald, Energy Control Company, 5 Beekman St., New York 38, N. Y.

The JACC Steering Committee comprises: D. M. Boyd of AIChE, E. R. Behn of AIEE, Mr. Archibald of ASME, J. E. Ward of IRE, and R. K. Adams of ISA. The Operating Committee for 1960 is composed of Mr. Archibald, general chairman; J. M. Mozley, program; and W. E. Vannah, publicity.

MSM Student Branch Is Host to District Contest

The Missouri School of Mines (MSM) Student Branch of the AIEE served as host this year for the annual District 7 student papers competition. The Institute promotes and sponsors these paper presentations as a means of training and stimulating future members of the electrical engineering profession.

Competing in the contest were outstanding students representing colleges and universities in the States of Arkansas, Texas, Kansas, Louisiana, New Mexico, Oklahoma, and Missouri. The contestants arrived at MSM on April 20 and were

welcomed at a "kick-off" banquet by J. W. Rittenhouse who is technical director of the Hi-Voltage Equipment Company and a former professor at the School of Mines.

The following day was spent in the presentation of papers by the various schools. That evening, an informal picnic was held at which students and faculty members got acquainted and talked over college life on the many different campuses represented in the contest.

The last papers were presented on the morning of April 21, and the winning paper was announced at a luncheon awards banquet. The selection of the best paper was made on the basis of technical quality and content as well as oral presentation.

The award committee consisted of five technical men from various industrial firms in the St. Louis area with D. K. Howell of Westinghouse as chairman. Mr. Howell presented the winner with a gift of $25 and a trophy commemorating the event.

All Branch contestants may also compete nationally in the Institute finals when the papers will be judged only on the basis of written style and content. A prize of $100 will be awarded to the national winner.

The first, second, and third prize winners in the annual District contest were as follows:

First Prize—F. H. Cleveland, Agricultural and Mechanical College of Texas, on the subject, "Determination of a Mathematical Formula for the Hysteresis Loop and the Computation of the Hysteresis Loss in Magnetic Materials by Numerical Methods."

Second Prize—Bill Jones, University of Arkansas, on the subject, "Atmospheric Whistlers."

Third Prize—Louis Thomason, Oklahoma State University, on the subject, "The Operational Amplifier as a Q Meter."

The panel of judges for the prize paper contest consisted of G. W. Fox, Union Electric Company; R. C. Chase, S. W. Bell Telephone Company; E. W. Logan, Emerson Electric Manufacturing Company; J. H. Rohlfing, Wagner Electric Corporation; and J. F. Clemens, Mc Donnell Aircraft Corporation, all from the St. Louis Section.

Long Island Engineer Heads New York Section, AIEE

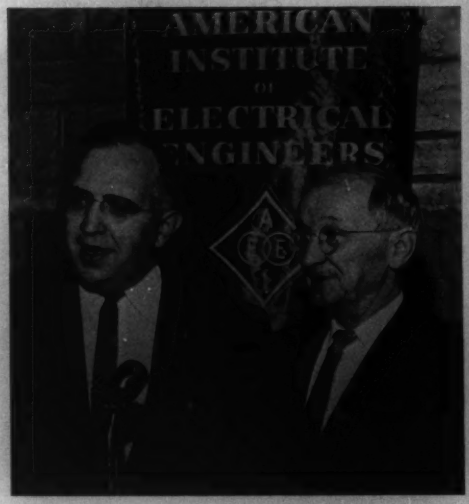
R. M. Franklin (AM '47), of Searington, N. Y., has been elected the 1960-61 chairman of the New York Section, AIEE. Mr. Franklin's election was announced April 26th at the annual meeting of the Section at the American Broadcasting Company (ABC) in New York, N.Y.

Following the meeting, the engineers heard an address by A. W. Malang, ABC video broadcasting engineer, on "A New Concept of Studio Lighting Control by a Solid-State Device."

Mr. Franklin, who is college relations and engineering training administrator for the Sperry Gyroscope Company at Great Neck, N. Y., is a native of Philadelphia, Pa., and a 1934 graduate of the Massachusetts Institute of Technology. His Section chairmanship becomes effective June 1, 1960.

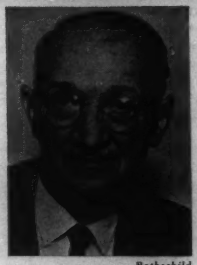
Other Section officers named were: B. B. Jordan (AM '39, M '48) Watchung, N. J., vice-chairman; J. C. Hoyt (M '45), Woodcliff Lake, N. J., secretary; W. G. Cheney (AM '48, M '58)) Rye, N. Y., treasurer; and A. B. Giordano (AM '40 M '57), Brooklyn Polytechnic Institute, Brooklyn, N. Y., and A. E. Joel, Jr. (AM '42, M '48), South Orange, N. J., members at large.

The New York Section includes Metropolitan New York, North Jersey, Long Island, Westchester, and the Hudson Valley. With almost 7,000 members, it is the largest of the 114 Sections of the AIEE.



AERO-SPACE Systems of the Future was the topic of F. W. Lowry's talk at the March 8 dinner meeting of the Los Angeles Section, AIEE. Mr. Lowry is manager, advanced systems application department, Westinghouse Electric Corporation at Lima, Ohio. Shown discussing the meeting are: Mr. Lowry (left) and Robert Milmoe, AIEE vice-chairman.

Rothschild



Rothschild

Robert Milmoe

Los Angeles Section Elects Chairman for 1960-61

Robert Milmoe, Bechtel Corporation, has been elected chairman of the Los Angeles Section, AIEE, for the year 1960-61, beginning June 1, 1960. The announcement was made by Fred Foulon, outgoing chairman, at the Section's annual "Ladies Night" banquet, Disneyland Hotel, Anaheim, Calif. The local Section consists of more than 2,800 engineer members from all fields of electrical engineering.

Mr. Milmoe, a graduate of Cornell University, is a registered professional electrical engineer, and served last year as vice-chairman of the Los Angeles Section. Since 1945, he has been with Bechtel Corporation, where he presently holds the title of supervising engineer.

Other officers elected at this time, in addition to Mr. Milmoe, are: vice-chairman—L. I. Grandi, professor of engineering, University of California at Los Angeles; secretary-treasurer—F. L. Goss, operation assistant electrical engineer, Los Angeles department of water and power; Director No. 1, Professional Development and Recognition—G. A. Davis, Southern California Edison Company; Director No. 2, Technical Operations—R. K. Collins, Westinghouse Electric Corporation; Director No. 3, Technical Operations—K. C. Dauwalder, Pacific Telephone and Telegraph Company; and Director No. 4, Administration—A. D. Crino, Allis-Chalmers Manufacturing Company.

Division chairmen will be chosen by their own groups, and committee chairmen and committee members will be appointed.

Prize Awards Highlight Lehigh Valley Section Meeting

The presentation of student prize paper awards and a discussion on the development of electric transmission highlighted the April 8 meeting of the Lehigh Valley Section.

The awards presented were for the sec-

Okonite Plant Viewed

MEMBERS and guests of the New Jersey Division and New York Section of the AIEE recently made a 2-hour inspection trip to the Paterson, N. J., plant of the Okonite Company, insulated wire and cable fabricating subsidiary of Kennecott Copper Corporation. In this photo are: *(left to right)* F. W. Nimmer, Ohio Edison Company; D. C. Emery, Allis-Chalmers Company, and Board of Education; T. A. Livingstone, Okonite Company; F. S. Sadler, Thomas A. Edison Research Laboratories; G. K. Morrison, retired; R. E. King, Federal Pacific Electric Company; and J. T. Zimnock, Okonite Company.

Pittsburgh Section Conference

AMONG those attending the Annual Dinner and Student Conference of the Pittsburgh Section, AIEE, on April 5 were: *(left to right)* W. H. Chase, District 14 vice-president; C. H. Linder, vice-president, General Electric Company, and speaker; L. W. Tarn, Pittsburgh Section chairman; Hendley Blackmon, AIEE director; and H. R. McNutt, Student Activities Committee chairman. Students from the University of Pittsburgh, Pennsylvania State University, Carnegie Institute of Technology, and West Virginia University participated in a prize paper contest.

ond annual Walter B. Morton Student Prize Paper Awards, made to the Lehigh Valley College students who write outstanding papers on electrical engineering subjects.

The late Mr. Morton was chief electrical engineer of the Pennsylvania Power and Light Company. The awards are sponsored by C. S. Brangan, president of the Bra-Bon Electric Company of Philadelphia, Pa. At this second annual awards presentation, D. L. Greene, vice-president of District 2, gave a brief history of the awards. John Roth of Allentown then announced the names of the winners.

The first prize of $100 was awarded to each of two teams of contestants. William Just and Allen Durling of Lafayette College received one first prize for their paper, "A Tube Characteristic Plotter." The other first prize went to John Ondria and Albert Dally of Lehigh University for their paper, "Analysis of a Cylindrical Cavity Resonator."

The second prize certificate was won by coauthors R. L. Kopski and E. T. Thompson, also of Lehigh, for the paper, "Development of a Transient Analyzer," and the third prize award certificate was won by D. T. Franck of Lafayette College for the paper "A Variable Pulse Generator."

Outstanding student awards were given to E. R. Tuttle of Lafayette, E. T. Thompson of Lehigh University and Robert Kressler of Bucknell University.

The Walter B. Morton award fund is arranged to endure for 20 consecutive years. The next awards will be made at Lehigh University in April 1961.

U.S. Committee Names Five Representatives to CIGRE

Five new United States representatives have been named to Technical Study Committees of CIGRE (International Conference on Large Electric Systems) by the U. S. National Committee, for the year 1960. The United States has 17 such representatives assigned to CIGRE groups working on subjects of broad international interest to electrical power system engineers. Each representative has a number of advisors to assist him.

The five new representatives for 1960, all either Fellows or Members of the AIEE, are:

J. H. Vivian (AM '34, F '48, chief electrical engineer, Southern California Edison Company—Study Committee No. 3. High Tension Switching and Circuit Breakers

E. L. Kanouse (AM '38, F '58), engineer-in-charge of design and construction, Department of Water and Power, City of Los Angeles—Study Committee No. 7. Transmission Towers and Tower Foundations and Design

L. R. Gaty (AM '39, F '50), vice-president, research and development, Philadelphia Electric Company—Study Committee No. 10. D-C Transmission at Extra High Voltage

G. P. Fallon (M '40), electrical engineer, Baltimore Gas & Electric Company—Study Committee No. 14. Carrier Current Transmission over Power Lines

R. J. Hopkins (AM '47, M '55), manager, power capacitor product engineering, General Electric Company—Study Committee No. 18. Series and Shunt Capacitors

The 18th biennial meeting of CIGRE will be held this year in Paris, France, June 15-25. United States engineers representing electric utilities and electrical manufacturing firms will author eight of the 130 technical papers on electric power generation and transmission that will be presented.

CIGRE is known among engineers by the initials of its French name—Conference International Des Grand Reseaux Electriques. The Paris-based association is the oldest and largest of international organizations for the interchange of engineering information among nations.

Joint Student Conference Held at the University of Alabama

The annual joint student conference of Districts 4 and 13 was held at the University of Alabama, April 6-9.

Presiding over the 3-day meeting were: Bruce Stephenson, chairman of the University of Alabama chapter; Prof. E. W. Winkler, North Carolina State College; Prof. J. L. Artley, Duke University; and Prof. G. W. Webb, Tulane University.

Registration figures listed 176 students and 25 faculty members representing 22 colleges of engineering from the 10 states in the two districts. On April 7, oral student paper presentations were held in the morning, an inspection trip of the B. F. Goodrich Rubber plant in the afternoon, and a barbecue at the Tuscaloosa Country Club in the evening. The paper contest was concluded the next morning, and was followed by an afternoon inspection trip to the Gulf States Paper Plant, and a banquet and dancing in the Student Union building. Business meetings closed out the conference on April 9.

The banquet and the subsequent presentation of awards climaxed the successful student conference. Certificates of participation were presented to the 14 student contestants before the district winners were announced. O. G. Gabbard, University of Kentucky, who discussed "A Low-Speed Thyratron Counter-Scaler Unit," and W. F. Chambers, Duke University, who presented "A Study of the Properties of Thin-Films of Iron-Colbalt at High Frequencies," were the respective winners from Districts 13 and 4. They will be presented to the Summer General Meeting of the AIEE at Atlantic City, N.J. A brief talk by Prof. Claudius Lee, counselor for 41 years, preceded the address by Dr. F. A. Rose, president of the University of Alabama.

EJC Supports Nominations for the Hall of Fame at NYU

Engineers Joint Council (EJC) has passed resolutions supporting the nominations of Sylvanus Thayer and Thomas A. Edison in the quinquennial election being conducted for the Hall of Fame for Great Americans at New York University.

The resolutions, which point out the homage due the two men by the engineering profession, were passed by the Council's Board of Directors April 22. The Board is the official governing body of the Council, representing 21 engineering societies, of which the AIEE is a constituent society, and 300,000 engineers.

Mr. Thayer has been nominated for the Hall of Fame category of "Educator." Mr. Edison's name has been submitted for the category of "Inventor." The Council resolution supporting Mr. Thayer pointed out his strong influence in establishing engineering education in the United States

District Champions

WINNER of the AIEE District 12 Student Paper Contest, the Northeastern University Student Chapter was presented a plaque by F. S. Bacon, Jr. (*right*), Winchester, AIEE vice-president. The winning paper was written by Joseph Panico, a 1959 graduate of Northeastern. (*Left to right*) D. E. Higginbotham, District chairman of AIEE Student Chapters, was present while R. P. Fischer, Walpole, president of the Student Chapter, received the plaque, and John Trott, faculty advisor at Northeastern, looked on. District 12 comprises all of New England and New York.

STUDENT prize paper contest winners of Districts 4 and 13 were: (*left to right*) E. R. Pledger, Georgia Institute of Technology, third place, District 4; O. G. Gabbard, University of Kentucky, first place, District 13; E. A. Meyers, Jr., Christian Brothers College, third place, District 13; Chan-Hue Yeh, Virginia Military Institute, second place, District 4; J. C. Price, University of Alabama, second place, District 13; and W. F. Chambers, Duke University, first place, District 4.

Ford Instrument Company

AS the journals arrive in large cartons from corporations, members of the Engineers Committee in the People-to-People Program sort the literature, first by title and then by placing the journals in the bins for the various universities.

while he served as superintendent of the U. S. Military Academy during 1817-33. Mr. Edison was praised for making possible the growth of the engineering profession through his inventions of electrical, electronic, and communications devices.

Nominations for the Hall of Fame can be made by any American citizen. Election is carried out by a board of electors composed of approximately 100 prominent individuals throughout the country. Established in 1900 as a gift to the American people, the Hall of Fame is administered by New York University.

Individuals chosen for the shrine must have been dead at least 25 years. They are designated by categories according to their careers. Only one person has been elected in the category of "Engineers and Architects." He is James Buchanan Eads (1820-1887), a civil and marine engineer, chosen in 1920.

The two resolutions, passed by EJC's Board of Directors, are as follows:

A Resolution

Relative to the admission of Thomas Alva Edison to the Hall of Fame for Great Americans at New York University.

WHEREAS, the name of Thomas Alva Edison, foremost American inventor, is now being considered for admission to the Hall of Fame for Great Americans; and

WHEREAS, the achievements of this most ingenious man of our century have made possible the electrical, electronic, and communications phenomena which so enrich the lives of mankind and add to the strength and well-being of our nation; and

WHEREAS, he is highly deserving of being admitted to the Hall of Fame for Great Americans; and

WHEREAS, Engineers Joint Council, composed of 21 engineering societies representing 300,000 engineers, wishes to acknowledge the tribute due him by the engineering profession, which, both directly and indirectly as a result of his technical discoveries, has assumed a position of vital responsibility in human affairs. Further, since his life and humanitarian contributions exemplify the primary objective of the Council: ". . . To advance the general welfare of mankind through the resources and creative abilities of the engineering profession."

THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF ENGINEERS JOINT COUNCIL that this body hereby respectfully requests and urges that Thomas Alva Edison be admitted to the Hall of Fame for Great Americans at New York University.

BE IT FURTHER RESOLVED that the Secretary of the Council is hereby instructed to transmit suitable copies of this resolution to the proper authorities.

Read and Adopted April 22, 1960

A. B. Kinzel, *President* — L. K. Wheelock, *Secretary*

A Resolution

Relative to the admission of Sylvanus Thayer to the Hall of Fame for Great Americans at New York University.

WHEREAS, the name of Sylvanus Thayer, pioneer in engineering education in the United States, is now being considered for admission to the Hall of Fame for Great Americans; and

WHEREAS, the achievement of this great educator helped prepare men with the engineering skills necessary for the building of our nation, and placed engineering education on the high level necessary for the continuing growth and expansion of this country; and

WHEREAS, he is highly deserving of being admitted to the Hall of Fame for Great Americans; and

WHEREAS, Engineers Joint Council, composed of 21 Engineering Societies representing 300,000 engineers, is confident that his being so honored would be a great credit to the engineering profession which he did so much to establish, and which the Council today represents.

NOW, THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF ENGINEERS JOINT COUNCIL that this body hereby respectfully requests and urges that Sylvanus Thayer be admitted to the Hall of Fame for Great Americans at New York University.

BE IT FURTHER RESOLVED that the Secretary of the Council is hereby instructed to transmit suitable copies of this resolution to the proper authorities.

Read and Adopted April 22, 1960

A. B. Kinzel, *President* — L. K. Wheelock, *Secretary*

Technical Journals Needed in "People-to-People" Program

"People-to-People" is a program of international friendships between Americans and the people of other lands. The program was started in 1956 and has had the constant support of President Eisenhower.

Scientists and Engineers make up one of the categories which support this massive program of communication. Other fields of international exchange involved in the program include health, farm, business, cultural, labor, religious, sports, military, and service organizations. More than 1,000 men and women are members of 33 committees functioning in a continuous effort to establish international friendship through this program.

Completely nonpartisan and outside governmental control, the People-to-People program depends upon the Americans' willingness to give time and effort to the cause of international friendship and peace.

The individual's contribution may take the form of letter writing, sharing books and magazines with people in foreign countries, promoting an affiliation between hometown and some foreign community, inviting foreign visitors to enjoy the hospitality of an American home, or working through business, civic, social, or cultural organizations that are endeavoring to promote international friendship and understanding.

Insuring that universities get periodicals that suit their individual needs is the most important element in the work of the program's Scientists and Engineers Committee. R. B. Lea, a former vice-president of Sperry Gyroscope and co-ordinator of exports for the Sperry Corporation who retired in 1956, is vice-chairman of the Scientists and Engineers Committee.

Journals published by the mechanical, civil, electrical, mining, and petroleum engineering societies, are the publications needed in the largest quantities by the Middle East engineer who is concerned with harnessing natural resources, building roads, hospitals, and schools, and getting industry started.

The machinery of collection and shipment works in this way: Individuals in several large engineering organizations, including Anaconda, American Cyanamid, Sperry Rand, and others, donate their personal copies of journals. Publishers contribute their unsold copies, and technical societies supply their surplus preprints of papers. At a Long Island warehouse where space has been donated by Sperry Rand, publications are sorted by volunteers, among whom are the retired scientists and engineers. They prepare shipments from lists sent by the universi-

ties. The complex paperwork for customs clearance is also donated by Sperry Rand. Cartons are transported free to the Middle East by private shipping companies or Navy ships. Mr. Lea writes to the recipients, describing the shipment and identifying special donors. The universities arrange transportation from ship to campus. Students and the universities' staffs get first choice of periodicals. Libraries get books and bound sets of transactions.

Technical journals and textbooks that are donated should be sent to: Engineers People-to-People Program, 36-02 Northern Boulevard, Long Island City 1, N. Y.

EJC Surveys Practices Regarding Proprietary Rights

The engineer generally is expected to determine for himself what information gained on one job he may utilize on a subsequent job, while he bears in mind that he or his new employer may later be held legally accountable, according to a survey made by the Employment Conditions Committee of Engineers Joint Council (EJC).

Entitled "A Survey of Employer Practices and Expectations Concerning the Safeguarding of Proprietary Rights," the Committee's report presents the results of a questionnaire submitted to 800 major industrial companies.

Responses indicate that wide use is made of employment agreements which protect the current employer, but that only in rare instances are previous employee agreements investigated. "These former agreements, however, can and have formed the basis for legal actions with both the engineer and new employer as defendants," the report pointed out.

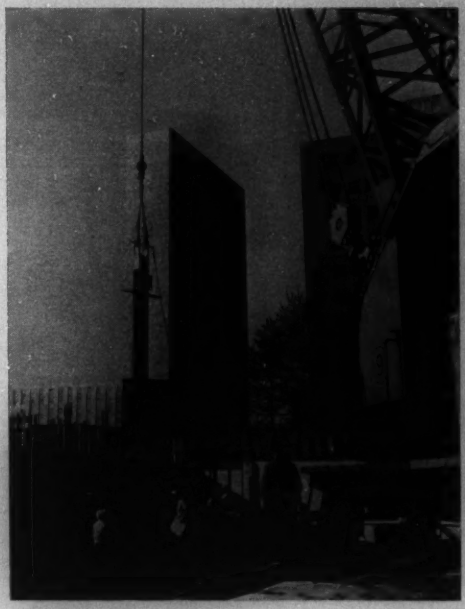
Almost one half of the employers responding disclosed that they use employee agreements to cover patent assignments and nondisclosure of proprietary information. Due to the difficulty in defining what constitutes trade secrets and confidential company information, inquiry was made to determine what type of instruction is given to employees. About half of the employers feel their areas of confidential information are generally defined. Only 20% give specific descriptions to new employees, and less than 5% explicitly cover in termination interviews what is considered confidential information.

As in the case of the new employee, comments indicate a general attitude that reliance is placed almost solely on the terminating employee to distinguish between proprietary and general information.

Single copies of the report may be obtained free from EJC. Costs of bulk quantities are available on request.

Support the New United Engineering Center

First Structural Steel Placed



THE first steel column in what will be the 20-story United Engineering Center was put in place at First Avenue and 47th Street in New York City on April 29. The $12 million stainless steel and glass structure is scheduled for completion in mid-1961. Thirty-three-hundred tons of steel will comprise the all-welded frame. The general contractor is Turner Construction Company. Dreier Structural Steel Company, Inc., of Long Island City, is fabricating and erecting the steel framework. The architects are Shreve, Lamb & Harmon Associates. Seelye, Stevenson, Value, and Knecht are the structural engineers.

United Press International

UET Seeks Contributions for the United Engineering Center

"Six weeks after his 85th birthday I took this picture *(below)* of Herbert Hoover breaking ground for the United Engineering Center on United Nations Plaza. In the cold rain, 'The Chief' stood bareheaded, patient while a score of photographers called "Hold it, please; just one more!" A thousand people turned out to witness this significant ceremony despite the miserable weather.

"Prior to this historic event Mr. Hoover had given freely of his time to assist the

THIS picture of the ground-breaking ceremonies for the United Engineering Center was taken by W. J. Barrett, past president of the AIEE and of the United Engineering Trustees, Inc. (UET). Appearing with Former President Herbert Hoover were: Jerry Fujimoto *(left)*, Hawaii-born engineering student, and Andrew Fletcher *(right)*, president of the UET.

societies' representatives on the board of United Engineering Trustees, Inc., in connection with the choice of a location for the center, the acquisition of the land, and the organization of the drives to raise money for the project. He had also made a generous financial contribution.

"All of these things 'The Chief' did because of his sincere interest in the welfare of the profession and of the societies and because of his appreciation of their importance to the nation. Constituting as they do a huge university for the advancement of the engineering art and science and for the continuing education and development of engineers, the societies are an important factor in the defense of our way of life during this age of technological 'cold war'.

"The total cost of the Center and related expenses will be approximately $12,560,000. We now have in hand or pledged all but about $1.5 million of this sum. Won't you please reach for your check book, write a check payable to United Engineering Trustees, Inc., and send it to the secretary of your society? If you prefer, ask the secretary of your local section for a pledge card and choose your own terms of payment. If you can add to a previous contribution, please do so. The United Engineering Center building will be ready for occupancy by mid-1961. Won't you help to have it paid for by that time?"

W. J. Barrett
Past President, UET and AIEE

Lamme Medal 1960 Nominations Due November 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal to be awarded early in 1961, may be submitted by any member in accordance with section 1 of Article VI of the bylaws of the Lamme Medal Committee as follows:

"The committee shall cause to be published in one or more issues of *Electrical Engineering*, or of its successors, each year, preferably including the June issue, a statement regarding the Lamme Medal and an invitation for any member to present to the Secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his 'meritorious achievement' and the names of at least three engineers of standing who are familiar with the achievement."

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee, to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

Article V, section 2, specifies that:

"The committee in making the award shall carefully observe the limitations imposed by Mr. Lamme, that the recipient must have 'shown meritorious achievement in the development of electrical apparatus and machinery.' This shall be taken to mean that the meritorious achievement must be of such character that it has resulted or will result in the production of substantially improved electrical apparatus or machinery. Any work which meets this requirement is admissible whether it be (a) in development of the theory involved; (b) in development of the characteristics of the materials employed; (c) in development of over-all design; or (d) in development in other ways which results in substantial improvement in electrical apparatus or machinery. The words 'electrical apparatus or machinery' shall be taken to indicate discrete and self-contained devices which may or may not include mechanical moving parts without limitation as to the field of application. They shall not be taken to include transmission or distribution systems as a whole, but rather to include the apparatus and machinery that is used in making up such systems."

AIEE PERSONALITIES

J. R. Bradburn (M '50), who has been vice-president and general manager of the ElectroData Division of Burroughs Corporation, has been named vice-president—manufacturing and engineering. He has line responsibility for all former Burroughs Division plants in the Detroit area; ElectroData Division's plant in Pasadena, Calif; Electronic Tube Division, Plainfield, N. J.; Electronic Instruments Division, Philadelphia, Pa.; and Control Instrument Company, Brooklyn, N. Y. Mr. Bradburn also has staff responsibility for all other manufacturing activities. **Irven Travis** (M '46), who has been staff vice-president—research and engineering, has been named vice-president—research of Burroughs Corporation. The change will permit him to devote his entire time to corporate research activities with responsibility for the laboratories at Paoli, Great Valley, and Howellville, Pa.

P. L. Johnson (AM '30, F '43), assistant vice-president of Pacific Telephone in Los Angeles, Calif., will retire from his position on May 1, 1960. He started his telephone career as an equipment installer with Pacific Telephone in 1923. He moved through a succession of operating and engineering assignments until, in 1941, he was named chief engineer. In this assignment, he directed the company's engineering activities in Southern California and Southern Nevada through the difficult war years until mid-1945, when he was appointed general plant manager. Southern California's rapid post-war growth produced high work levels in construction, installation, and maintenance activities for which he was responsible. At the end of 1957, Mr. Johnson was named assistant vice-president, operations, his title at retirement.

Karl Kelly (AM '51) has been named manager of the Pittsburgh district sales office of I-T-E Circuit Breaker Company, Philadelphia, Pa. Mr. Kelly was previously manager of I-T-E's Buffalo, N. Y., district office.

William Kerr (AM '43, M '52), a member of the University of Michigan engineering faculty since 1948, has been appointed an associate Director of the Michigan Memorial Phoenix Project. The appointment, which extends to June 30, 1960, fills the vacancy created when **H. J. Gomberg** (AM '43, M '52) was named director. Prof. Kerr's assignment involves work with the University of Michigan faculty in the development of the research program on peace-time atomic energy uses and negotiation with industry and Government for participation of the Phoenix Project in outside research. He has served on the following AIEE Committees: Nucleonics (1955-57, 1959-60), Basic Sciences (1956-60), Nucleonic and Radiation Instruments 1957-60), and Nuclear Congress and Nucleonics (1959-60). Mr. Gomberg has served on the AIEE Nucleonic and Radiation Instruments Committee (1957-60).

N. O. Kirby (AM '58) has been appointed general manager of the G & W Electric Specialty Company, Blue Island, Ill. He joined the company in 1957 as manager of engineering.

W. E. Korsan (AM '39, M '48) has been appointed assistant manager of the industrial systems department of Allis-Chalmers Manufacturing Company, Milwaukee, Wis. He has been with Allis-Chalmers since 1942.

R. J. Kuhn (M '31), consulting engineer of New Orleans, La., is the recipient of the Louisiana Engineering Society Technological Accomplishment Medal for 1960.

F. C. Lindvall (AM '26, F '43), chairman of the Division of Civil, Electrical, and Mechanical Engineering, and Aeronautics at the California Institute of Technology, has been elected to the board of

directors of the Marquardt Corporation. Dr. Lindvall has held his present post since 1945. He has served on the AIEE Education Committee (1951-60).

F. C. Ludington (M '48), manager of the Allis-Chalmers Manufacturing Company's control department, will retire on July 1, 1960. Mr. Ludington has been associated with Allis-Chalmers since 1923. He became manager of the control department in 1945 and was manager of the Allis-Chalmers Hawley Works during 1951-55. He will serve as a consultant until his retirement.

A. W. Melloh (AM '38, M '45) of the University of New Mexico faculty has been named professor of electrical engineering and dean of the State University of Iowa College of Engineering by the State Board of Regents. Prof. Melloh's appointment will be effective July 1, 1960.

W. R. Meoli (AM '52) has been appointed vice-president and sales manager of Veeco Vacuum Corporation, New Hyde Park, N. Y. Mr. Meoli joined the company in 1955 and has served as Chicago regional sales manager and assistant sales manager.

H. A. Moench (AM '31, M '38, Member for Life), dean of engineering and head of the electrical engineering department at Rose Polytechnic Institute in Terre Haute, Ind., has become chairman of the Indiana State Board of Registration for Professional Engineers and Land Surveyors.

M. E. Mohr (AM '39, M '53) has been appointed vice-president, operations, for Ramo-Wooldridge, a division of Thompson Ramo Wooldridge Inc., Canoga Park, Calif. He was formerly vice-president of engineering of the Ramo-Wooldridge Division.

A. L. Penniman, Jr. (AM '15, F '43, Member for Life), has retired from his post of vice-president, electric operations, for the Baltimore Gas and Electric Company, Baltimore, Md. Mr. Penniman has been associated with the utility since 1911, first as a draftsman, then as a testman, and later as an inspector in the company's Electric Division. Within 3 years after joining the company, he was made superintendent of Steam-Electric Generating Stations. In 1937, he became general superintendent, electric operations, with the over-all responsibility for planning, design, construction, and operation of all electric properties of the company. He had been vice-president since 1950.

C. A. Reeb (AM '43), western manager of the Kerite Company, has been appointed assistant to the president of the firm. Mr. Reeb joined Kerite 48 years ago. **D. E. Skyllingstad** (AM '38, M '50) has been appointed assistant western manager. Mr. Skyllingstad became associated with Kerite in 1946.

L. S. Schwartz (AM '45, M '48), adjunct professor of electrical engineering at New York University's College of Engineering, has received a contract from the U.S. Air Force Cambridge Research Center to carry on research in electronic feedback communications systems. Mr. Schwartz is a senior research scientist in the college of Engineering's Research Division and project director of an electrical engineering research team of the department of electrical engineering. He has served on the AIEE Communication Theory Committee (1957-60, chairman 1959-60) and Communication Division Committee (1959-1960).

K. F. Scheult (M '51) has been appointed chief engineer of the Trinidad & Tobago Electricity Commission, Port-of-Spain, Trinidad, West Indies. Mr. Scheult has been with the electricity supply industry for 32 years. He joined the Trinidad Electric Company, Ltd., in 1928. Formerly superintendent of the Distribution Division, Mr. Scheult was assigned to the new post of chief engineer which was created to control the commission's two engineering divisions responsible to the general manager for the generation and distribution of electric energy in Trinidad and Tobago.

E. W. Sheridan (AM '41), previously with Radio Corporation of America, has joined the Link Division of General Precision, Inc., Binghamton, N. Y., as manager of Eastern Laboratories.

D. R. Shoults (AM '35, F '48) has been appointed representative, atomic development, for the General Electric Company, New York, N. Y. Mr. Shoults fills the position vacated by **F. K. McCune** (AM '33, F '49) when the latter was appointed to head the company's engineering services. Mr. Shoults is responsible for delineating and representing General Electric's overall position in commercial atomic energy work both in the United States and abroad. Since 1951, Mr. Shoults had been general manager of the General Electric aircraft nuclear propulsion department at Cincinnati, Ohio. He served on the AIEE Air Transportation Committee (1942-45, chairman 1944-45).

D. B. Sinclair (M '45, F '51), formerly vice-president and chief engineer of the General Radio Company, West Concord, Mass., has been appointed executive vice-president and technical director of the company. **A. E. Thiessen** (M '41), previously vice-president, has been named chairman of the board. **I. G. Easton** (AM '41, M '49), formerly engineering manager, has been appointed vice-president for engineering. Mr. Easton has served on the AIEE Electronic and High Frequency Instruments Committee (1956-60).

N. S. Spencer (AM '39), who held the position of sales manager of the switchboard section of the Switchgear Division, has been appointed manager, utility marketing, of I-T-E Circuit Breaker Company, Philadelphia, Pa. At the same time, **W. A. Donaldson, Jr.** (AM '47, M '54), previously manager of contractor sales, switchboard section, was named to succeed Mr. Spencer.

P. R. Sprowl (AM '41, M '48) has been appointed manager of industry engineering and **M. B. Wyman** (AM '30, F '42) has been appointed manager of service of the Westinghouse Electric Corporation, East Pittsburgh, Pa. The new appointments are a result of the division of the engineering and service activities of the corporation's apparatus products group. Mr. Sprowl had been director of engineering for the ap-

Alex Dow Award Presented

Detroit Edison Company

DETROIT Edison Company's annual Alex Dow Award for outstanding achievement was presented to *(right)* L. I. Komives (AM '41, F '54) by *(left)* W. L. Cisler (M '35, F '47), Edison president, at a banquet in Detroit, Mich., on April 5. Mr. Komives, assistant general superintendent of underground lines for Edison, was honored for his work in organizing an electrical industry group which is responsible for the design and construction of facilities for testing extra-high voltage underground cables.

paratus products group. Mr. Wyman was formerly manager of the engineering and service department. Mr. Wyman has served on the following AIEE Committees: Special Committee on Registration of Engineers (1944-46, 1959-60) and Professional Conduct (1958-60).

B. R. Stack (M '56) has been promoted from project engineer to manager of military projects of International Telephone and Telegraph Corporation Laboratories, Palo Alto, Calif. He has served on the AIEE Wire Communications Systems Committee (1956-60).

E. R. Summers (AM '38, M '44), senior development engineer in General Electric's medium a-c motor and generator department, Schenectady, N. Y., has been presented with a special award of merit, first ever given by the department. Mr. Summers invented and perfected a new water lubrication system for motors that drive atomic reactor pumps.

J. M. Thompson (AM '48, M '54) has been appointed vice-president and general manager of Itemlab, Inc., Port Washington, N. Y. Mr. Thompson resigned from his government post of chief of the test facilities laboratory at Rome Air Development Center, Rome, N. Y.

H. E. Turner (AM '26, M '41) has been elected a member of the board of directors of the American Electric Power Company, New York, N. Y. Mr. Turner is an executive vice-president for operations of the American Electric Power Service Corporation, a subsidiary company of the American Electric Power System.

J. E. Voyles (AM '46) has joined the Ramo-Wooldridge Division of Thompson Ramo Wooldridge Inc. as district representative in the division's Washington, D. C., field office.

S. L. Weiner (AM '52) has been advanced from product planning manager to product engineering department head at the Sperry Semiconductor Division, Sperry Rand Corporation, South Norwalk, Conn.

J. O. Weldon (M '56) has been elected to the board of directors and named to the executive committee of Ling-Altec Electronics, Inc. Mr. Weldon is president of Continental Electronics Manufacturing Company, Dallas, Texas, which was founded in 1947 and became a subsidiary of Ling-Altec in 1959.

K. R. Wendt (M '52) has been named manager of the research department of Colorado Research Corporation, Broomfield, Colo. Mr. Wendt was formerly associated with the Martin Company, Denver Division, where he was chief engineer of the Communications and Radar Section.

H. A. Wheeler (F '46), president of Wheeler Laboratories, Inc., Great Neck, N. Y., received the 1960 Distinguished Engineer Alumnus Award from George Washington University, Washington, D. C., at ceremonies on February 24, 1960. Mr. Wheeler delivered the annual Frank A. Howard Lecture to members and friends of the Engineer Alumni Association. He spoke on the subject of radio communication with submarines. The Distinguished Engineer Alumnus Award is given annually to a graduate of the George Washington Engineering School who has made notable contributions to his profession.

H. J. White (M '49), previously director of research and development, Research-Cottrell, Inc., Bound Brook, N. J., has accepted an appointment as professor of applied science at Portland State College, Portland, Oreg. Dr. White remains a member of the board of directors of Research-Cottrell and will continue to serve in his capacity as a consultant to the company.

C. E. Wood (AM '54) has been appointed district manager of the Miami, Fla., sales office of I-T-E Circuit Breaker Company. Mr. Wood joined I-T-E in 1953 as a sales representative for the company's resale line in the Philadelphia, Pa., district office. In 1957, he became head of the Philadelphia district office resale market group.

C. J. Woodka (AM '52) has been named market research specialist for Motorola's Semiconductor Products Division. Prior to joining Motorola, Mr. Woodka was associated with Wright Air Development Center's programming office as a staff engineer.

M. M. York (AM '43, M '54) has been appointed manager of marketing of the Industrial Equipment Division of Allis-Chalmers Manufacturing Company, Milwaukee, Wis. He was formerly manager of the North Central Region.

R. L. Zahour (AM '53, M '55) has been named manager of lamp applications for Westinghouse Electric Corporation's lamp Division in Bloomfield, N. J. He was previously manager of illuminating engineering of the Westinghouse Lamp Division. Mr. Zahour has served on the AIEE Production and Application of Light Committee (1955-60).

OBITUARIES

James A. Crist (AM '41, M '48), supervising engineer—customer equipment, New York Telephone Company, New York, N.Y., died recently. He was born March 26, 1902, in New York. In 1924, he was employed by the New York Telephone Company as an outside plant engineer, a position he held until 1928 when he became division transmission engineer. He was promoted to staff engineer—maintenance methods in 1933, and in 1938 to staff engineer—construction and engineering methods. During World War II, he was a lieutenant colonel in the U. S. Army Signal Corps where he supervised communication equipment operation and maintenance and technical training. In 1946, Mr. Crist returned to the company as engineer—staff functions. His duties were the supervision of technical operations in connection with television and radiotelephone projects and the preparation of studies of construction requirements of telephone cable projects. He was later advanced to the position of supervising engineer in charge of customer equipment. Mr. Crist served on the AIEE Membership Committee (1956-58.)

George Richard Davies (AM '55), electrical engineer with the British Columbia Power Commission in Victoria, in the province of British Columbia, Canada, died recently. He was born December 14, 1927, in Wrexham, North Wales, and received the degree of bachelor of applied science in electrical engineering from the University of Toronto in 1953. Prior to joining the British Columbia Power Commission in 1956, he was employed by the Toronto Hydro-Electric System, Toronto, Ont. He was first employed by Toronto Hydro in 1953 as a graduate engineer-in-training assigned to the station planning and design department. He was a registered professional engineer in Ontario.

Benjamin Atwood Fisher (M '45), associate professor of electrical engineering at the Illinois Institute of Technology, died recently. Mr. Fisher was born October 27, 1899, in St. Louis, Mo. He received the B.S. degree in electrical engineering in 1924 from the University of Missouri, and the M.S. and professional degrees in electrical engineering in 1929 and 1930, respectively, from Iowa State College. In 1937, he was awarded the M.S. degree in electrical communication engineering from Harvard University. During 1924-25, he was an instructor in electrical engineering at the University of Nevada. The following year, he was employed as an electrical test man for the General Electric Company, Schenectady, N. Y. He taught electrical engineering in 1926-27 at the South Dakota State College. In 1927-41, he was, successively, assistant professor, associate professor, and professor of electrical engineering at Oklahoma Agricultural and Mechanical College, where he initiated and was in charge of the communication option in the electrical engineering department. During World War II, he was officer-in-charge of the Deperming Station and Magnetic Calibration Range, New Orleans, La. He became an instructor in electrical engineering at the U. S. Naval Academy in 1943 where he taught until 1946, when he became a professor at the University of Denver. He took the position of associate professor at the Illinois Institute of Technology in 1948 and taught there until his death. Mr. Fisher was a member of the American Society for Engineering Education and a senior member of the Institute of Radio Engineers. He was a registered professional engineer in the State of Illinois and a counselor for the AIEE Student Branch at the Illinois Institute of Technology (1954-59).

Arthur Lucas Jones (AM '07, M '26, F '38, Member for Life), consulting engineer of Denver, Colo., and a vice-president of the General Electric Company until his retirement in 1945, died recently at the age of 80. He was born May 22, 1879, in Ballston Spa, N. Y., and graduated from Cornell University in 1904 with the degree of mechanical engineer. He specialized in

electrical engineering. Mr. Jones was employed in the testing department of General Electric, Schenectady, N. Y., in 1904. He was transferred to the power and mining engineering department in 1907. He went to Denver in 1907 as Rocky Mountain District engineer, responsible for engineering at Denver; Salt Lake City, Utah; and Butte, Mont. In 1926, he was appointed assistant district manager, and in 1928, district manager. Mr. Jones was appointed commercial vice-president in 1936 and continued his duties as district manager. He was active in the building and operation of Radio Station KOA by General Electric.

Raymond Earl King, Jr. (AM '53), supervisory engineer for the aircraft equipment department of the Westinghouse Electric Corporation, Lima, Ohio, died recently at the age of 33. He was born April 3, 1926, at Wooster, Ohio, and was educated at Wooster College and at the Massachusetts Institute of Technology, from which he received the B.S. degree in electrical engineering in 1952. Mr. King joined the Westinghouse graduate student program in 1952, and in 1953 was assigned to the aircraft equipment department as a design engineer. In this position, he did preliminary design work on transformer-rectifier units for aircraft, and later was the project engineer on the first regulated high-power transformer-rectifier power supply using silicon rectifiers. Mr. King was advanced to supervisory engineer in 1958, in which position he headed the conversion equipment group of the Westinghouse Aircraft equipment department. He was chairman of the SAE-A2Z subcommittee on conversion equipment and was secretary of the Lima Section AIEE.

Harold John Lockwood (M '38), Hallden professor of engineering at Trinity College, Hartford, Conn., died recently. He was born in 1890 in New Rochelle, N. Y., and received the electrical engineering degree in 1912 and the M.S. degree in 1916, both from Lafayette College. During 1912-21, he was an instructor and assistant professor of physics at Lafayette College. In 1921, he became professor of power engineering at Dartmouth College. Mr. Lockwood became a consulting engineer for the state of New Hampshire in 1931, assigned to purchasing methods, specifications, the operation of state institutional plants, and the selection of new equipment. He was state director of Maine, New Hampshire, and Vermont for the Federal Administrator of Public Works during 1933-37. In 1938-42, he was professor of electrical engineering at Manhattan College. Before joining Trinity, he was employed as supervisor of ship repairs for the Todd Shipyard Corporation. Prof. Lockwood became associated with Trinity in 1943 as chairman of the engineering department.

Bruce Robinson Prentice (M '47), overseas representative in Europe for the General Electric atomic power equipment department, died recently. Mr. Prentice was born May 24, 1906, in Clifton, Kans., and received the B.S. degree in electrical engineering from Kansas State College in 1930. The following year, he participated in the General Electric student test course for graduate engineers, and this was followed with assignments in the General Electric advanced engineering program, in which he was a supervisor. In 1939, he became requisition engineer in the Aeronautics and Marine Engineering Division; in 1941, engineer in charge of the Aeronautics Equipment Section; in 1943, assistant to the engineer of the Aeronautics and Marine Engineering Division; in 1946, assigned to Apparatus Design Engineering; and later in 1946, assigned to the executive department of the Engineering Policy Division in charge of co-ordination of engineering and other matters on atomic power development programs. Mr. Prentice had been stationed in Geneva for the last 2 years. Before going to Geneva, he was manager of the company's nuclear systems design study. Mr. Prentice was responsible for work leading to the choice of the boiling water reactor power plant as the company's first line contender for entry into the commercial atomic power plant field. He was a member of the American Nuclear Society, the American Society of Mechanical Engineers (ASME), and the Engineers Club of New York, N. Y. In 1957, Mr. Prentice was chairman of the executive committee of the ASME's nuclear engineering division, and was general chairman of the 1958 Nuclear Congress in Chicago, Ill. He served on the AIEE Nucleonics Committee (1946-49).

Charles Thurston Razor (M '48), head of the electrical engineering department at the Citadel, Charleston, S. C., died recently. He was born October 8, 1900, in Salt Lick, Ky., was educated at the Universities of Kentucky and Michigan, and from the latter received the M.S. degree in electrical engineering in 1943. In 1926, he was appointed assistant professor of physics at the Citadel, and in 1930 was given full charge of courses in electrical engineering for students specializing in physics. The following year, he introduced courses in d-c circuits and machines and a-c circuits and machines for students of civil engineering. He became associate professor of physics in 1937, and professor of physics and department head in 1943. At this time, Mr. Razor was designated as interim professor of electrical engineering and authorized to sponsor and direct the development of a department of electrical engineering as soon as this activity could be resumed. In 1947, he served in a dual role, directing the work of the physics and electrical engineering departments and teaching a full schedule of courses in electrical engineering. Mr. Razor became head of the electrical engineering department in 1953 when it was separated from the physics department.

William Edward Vogelback (M '25), consulting industrial engineer, Chicago, Ill., died recently. He was born June 9, 1890, at New York, N. Y. In 1910, he was employed in the engineering department of Sanderson & Porter, New York, as a junior engineer and draftsman. He was promoted to assistant engineer in 1914, assigned to inventory and appraisal of electric railways, power and light properties, in Northern Ohio. In 1915, he was transferred to the Chicago office. In 1917, he became an assistant to F. B. H. Paine of Paine, McClellan & Campion, engineers of New York and Philadelphia, Pa. He was squadron commander in World War I and chief of the glider program of the War Production Board during World War II. During 1919-20, he was a consulting engineer for public utilities and industrials, and in 1920, returned to Sanderson & Porter where he was appointed assistant manager in Chicago, Ill. In 1924, he became consulting engineer and associate of the firm of Spooner & Merrill, Grand Rapids, Mich., and Chicago, Ill. He served as president of the American Engineering Management Corporation, the Alaska Public Utilities, and the Indianapolis Broadcasting Company, and was president and major stockholder of the Union Gas & Electric Company, Bloomington, Ill., from 1944 until its merger with Northern Illinois Gas Company in 1955.

Lynn Bodien Wallis (AM '30), master mechanic of the Holly Sugar Corporation, Delta, Colo., died March 1 at the age of 63. He was born July 24, 1896, at Johnson, Kans., and received the B.S. degree in electrical engineering from the University of Colorado in 1925. He was employed by the Holly Sugar Corporation at Swink, Colo., as an electrician in 1925. The following year, he was transferred to the Torrington, Wyo., plant of the corporation, and in 1927, became electrician and power plant operator of the Torrington plant. In 1928, he became assistant to the chief electrician in Torrington. Mr. Wallis worked several years at the Sheridan, Wyo., plant, 1 year at the Sydney, Mont., plant, and approximately 5 years at the Swink plant. He was transferred to the Delta, Colo., plant in 1958.

Bogumil M. Wojciechowski (M '51), an engineer at Bell Telephone Laboratories, Murray Hill, N. J., died recently. Born April 18, 1907, in Pilica, Poland, Mr. Wojciechowski was a graduate of the Politechnic University of Warsaw from which he graduated as an electrical engineer in 1936. He also studied at the Sorbonne in Paris and at Columbia University. He was an instructor of physics and radio communications at the Polytechnic University of Warsaw during 1936-38. He was an engineer in the National Institute of Telecommunication in Warsaw in 1937-39, when he developed testing methods for telephone equipment, and became section chief in 1939. He lectured on "Principles of Telecommunication" for the National College of Telecommunication in Warsaw during 1938-39. Mr. Wojciechowski was employed on the development of the communication systems for the French Navy as a research engineer of the "Industrielle des Téléphones" in Paris, France, in 1939-40. He was employed in the United States in 1942 as an engineer in the test set development department of the Western Electric Company, Kearny, N. J., where he was assigned to the development of testing methods and instruments for telephone equipment. He transferred to Bell Telephone Laboratories in 1955, where he worked on the development of high-precision communication testing instruments.

OF CURRENT INTEREST

Television Weather Satellite Begins Work as Part of Complex System

THE United States' TIROS satellite, carrying the nation's most advanced space-borne television "eye" to study the world's weather, is the information-gathering element in a complex satellite-and-ground system developed for the U.S. Government by the Radio Corporation of America (RCA).

THIS VIEW of the weather satellite's base plate from beneath shows the large lens of the wide-angle television camera, one of the two cameras carried in the satellite to observe cloud formations around the world, for direct transmission to the ground or for storage on television tape recorders in the satellite for transmission to the ground on command.

The satellite comprises perhaps the most elaborate electronics package yet sent into orbit around the earth, containing specially designed miniature television cameras, video tape recorders, transmitters, solar cell and rechargeable battery power supplies, and an array of control and communications equipment.

Speeding along its course in space, the satellite is linked to an extensive ground network of tracking and receiving stations, data-processing systems, and programming and control centers. Together, the satellite and ground equipment form a unified system to gather and analyze world-wide data on cloud formation in the earth's atmosphere.

The TIROS system, including the satellite and its associated ground network, was designed and constructed by scientists and engineers of RCA's Astro-Electronic Products Division at Princeton, N. J., under the general systems management of the National Aeronautics and Space Administration (NASA) and the technical direction of the U. S. Army Signal Research and Development Laboratory at Fort Monmouth, N. J. It evolved from the original concept of Vanguard II, a weather satellite developed by the Army Signal Corps for NASA. Signal Corps participation in the TIROS project is a highlight of the Corps' Centennial Year (see pp. 547-49 of this issue).

▲ *The* TIROS *weather satellite, one of the most complex electronic systems yet sent into outer space by the United States, contains complete television imaging, recording, and transmission equipment for gathering visual data on cloud cover and sending the pictures to earth. In this artist's drawing,* TIROS *is far above the Pacific. Symbol on horizon indicates one of the principal ground installations of the system at Fort Monmouth, N. J.*

Dr. E. W. Engstrom, senior executive vice-president of RCA, described the system as "a major achievement in space technology and in electronics for space." Said Dr. Engstrom:

"The success of TIROS stands as a tribute to the vision and skill of scientists and engineers in the Government and military services, in universities, and in industry."

The importance of the TIROS system as a new experimental tool for meteorologists was emphasized by Barton Kreuzer, manager, marketing, of the RCA Astro-Electronic Products Division, who said:

"The mission of TIROS satellite is the visual observation of cloud formations over large portions of the earth to produce new information about such weather phenomena as hurricanes, typhoons, and the movement of weather fronts. Besides providing unprecedented and comprehensive visual coverage of global weather on a swift and continuous basis, the satellite will give meteorologists for the first time a means of checking the accuracy of present weather reporting from ground stations around the world. Thus, it promises not only to lay the groundwork for new satellite weather services in the future, but also to increase the effectiveness of

present world-wide weather information gathering methods."

The path of the satellite, circling the globe from west to east about every 90 minutes at an altitude of about 400 miles, will permit cloud observations throughout a belt extending from the latitude of Santa Cruz, Argentina, in the south, to the latitude of Montreal, Que., Canada, in the north. During its planned operating lifetime of 90 days, the satellite is expected to complete about 1,500 orbits, covering every part of this belt many times.

Sequence of Operations

According to Sidney Sternberg, chief engineer of the RCA Astro-Electronic Products Division, the operation of the system involves the following sequence of three principal functions carried out by an intricate combination of electronic subsystems in the satellite and on the ground:

1. Preparation of a program and transmission of commands to the satellite at the start of each orbit, including instructions for picture-taking in specific areas of interest to the meteorologists.
2. Operation of the television and other equipment in the satellite during its passage, in response to the control commands received from the ground.
3. Read-out of the pictures and other information from the satellite on command from the ground at the completion of each orbit.

The principal ground stations are situated at Kaena Point, Hawaii, and Fort Monmouth, N. J. During all but three or four orbits each day, the satellite passes within range of one of the stations, permitting readout of information and programming of the satellite electronic apparatus for the next passage. In addition, two "backup" stations are situated at the Space Center of RCA's Astro-Electronic Products Division at Princeton, and at Cape Canaveral, Fla.

► THE drum-shaped satellite is placed on its side in a magnetic drag test device for measurements of the effect on the satellite of the earth's magnetic field. The effect is observed as the satellite is rotated on its axis between large magnetic coils whose effect approximates that of the earth's magnetic field at the distance in space at which the satellite moves in orbit.

The satellite itself was described by Mr. Sternberg as "a major space system complex" incorporating advanced concepts in space communications and the remote control of satellite functions. He pointed out that its development had required not only the design of new miniaturized television equipment and control devices, but also special methods of controlling the satellite's rate of spin, its attitude in relation to the earth's surface, and its thermal balance during the 90-day period. He gave the following summary of its principal features:

Shaped like a drum 42 inches in diameter and 19 inches in depth, the vehicle is covered on its top and sides with over 9,000 solar cells which generate electricity directly from sunlight to charge an assembly of small storage batteries that power the electronic equipment.

Two Complete TV Systems

The key function of the satellite is performed by two complete television systems capable of taking a series of still pictures of cloud formations during each orbit. Each employs a ½-inch Vidicon camera small enough to hold in the palm of a hand. One of the cameras is equipped with a wide-angle lens for viewing clouds in an area about 800 miles on each side. The other employs a narrow-angle lens to scan cloud details in a smaller area.

Linked to each camera is a miniature television magnetic tape recorder specially designed for satellite use. Each of the recorders stores up to 32 individual pictures taken by the camera during a single orbit. When the satellite passes within range of one of the ground stations, a command signal causes the information to be read from the tape into the satellite transmitter for transmission to the earth. For picturetaking while the satellite is within range of the station, the cameras can be instructed to feed their informa-

ABOVE: View of internal electronic system of the satellite before being covered by the cylindrical side and top structure bearing the solar cell power arrays. In foreground is one of the two television cameras, surrounded by various other subsystems for receiving, transmitting, and electronic switching functions. Two magnetic tape recorders for television pictures are installed under the transparent domes at the right and left. *Right:* The complete satellite is positioned for outdoor tests of its solar cell power supply.

tion directly to the transmitter rather than to the tape storage systems.

To permit meteorologists to identify the direction of each picture, the satellite carries a "north indicator" system which automatically measures the angle of the sun in relation to the vehicle. The resulting signal, sent to the ground with each picture, is processed by a "sun angle computer" and displayed on a television screen beside the picture to indicate the north direction of the image. In addition, an infrared detector on the satellite senses the crossing of the earth's horizons as the vehicle rotates at its spin rate of 12 revolutions per minute. This information also is transmitted to the ground and is processed to determine the attitude in space of the vehicle at the time of picture taking.

At the start of each orbit, the television cameras can be instructed electronically to photograph an area of specific interest—such as a typhoon center over the Pacific or a hurricane in mid-Atlantic. The instructions, prepared at the NASA Computing Center in Washington, D. C., in co-operation with specialists of the United States Weather Bureau, are sent to the ground stations. At the appropriate station, the program is sent in the form of radio signals to an "electronic clock" in the fashion of a remotely operated alarm clock, causing the cameras to start a sequence of operations at the specified time during the succeeding orbit, as the satellite passes over the region of particular interest.

As the satellite swings around the earth and comes again within range of a ground station, a command signal is sent from the ground for transmission of the cloud cover pictures stored on the tape. At the ground station, the information is displayed on a television picture tube and recorded on another magnetic tape system. The image on the picture tube also is photographed for further study and future reference by experts of the Weather Bureau and other services.

It was pointed out that the ground command and control system has been designed to permit either automatic or manual operation of the satellite system, or a combination of both. With automatic operation, the program for the orbit is preset and each step is started by the electronic clock control in the satellite. With manual operation, the commands are transmitted by an array of pushbuttons at the ground station, permitting direct operation of the television cameras while the satellite is within range, and providing an opportunity for checking individual satellite functions. By combining the two methods, the program is preset, but each sequence is started manually by pushbuttons at the ground station when the satellite is within range.

The TIROS system, including the satellite and its associated ground complex, was developed by Astro-Electronic Products Division engineering groups working under V. D. Landon and E. A. Goldberg, project managers. EE

Wear Your ◆ AIEE Badge

Security Has Been Lifted on Radar Mapping Systems

SECURITY WRAPS were removed recently from a radar development that should play an important role in deterring limited warfare—a side-looking radar that produces aerial maps of thousands of square miles of terrain per hour, night or day, in any weather in which man can fly. This radar, developed for the U.S. Air Force by Texas Instruments, Inc. (TI), gives United States field commanders near-photographic up-to-the-minute information on troop and material movements well behind aggressor front lines, and pin points targets scattered over wide areas.

Tactical Significance

In World War II and even the Korean conflict, armies relied heavily on visual observation and foot patrols to gather vital decision-making data for tactical planners. The increased mobility and firepower of today's armies has made these surveillance methods obsolete. Radar mapping gives immediate, day or night surveillance, and in so doing greatly strengthens our tactical forces as deterrents to limited warfare.

The mapping radar announced, designated *AN/APQ-55* by the Air Force, penetrates camouflage and "sees" through rain or fog with little or no degradation of the final pictures. Radar maps also can isolate moving targets to reveal the amount of activity in an area—information of obvious value to commanders planning air strikes or deployment of defensive forces.

In the *APQ-55* radar, the perspective of distance is adjusted electronically so that items at the edge of the photo are of the same scale as those at the center. In an aerial photograph, ground distances become compressed in perspective as the distance from the camera increases. Also, an aerial camera scanning a fixed angle will map less area as altitude decreases. The TI radar systems scan a constant ground area independent of altitude and can cover a wide area at low altitude, recording in fine detail with no perspective distortion.

Radar mapping provides field commanders with surveillance data within moments after the aircraft makes its pass. A new communications development by TI, a microwave data link, can transmit directly from the radar receiver and feed data back to a film recorder and processor at a remote combat post to provide field commanders and tactical air groups complete, up-to-the-moment information on aggressor build-ups and movements.

Nonmilitary Application

To date, systems have been flown by the Air Force, Signal Corps, and the Coast Guard. One of the uses of radar mapping came when the Coast Guard mapped icebergs in the North Atlantic shipping lanes. In the daily reconnaissance mission

RADAR MAP of Dallas, Texas, made by the *AN/APQ-55* surveillance radar developed for the U.S. Air Force by Texas Instruments, Inc. Downtown Dallas is at lower center, marked by radar shadows from the skyscrapers. Shadows here and from the bridges crossing the Trinity River help determine the height of these objects. The modern new Brookhollow Industrial Center is at extreme left just above center with Dallas Love Field at top.

required to cover this vast area, flights are handicapped by an almost constant fog layer which makes visual identification extremely difficult and/or dangerous. Identification was further complicated by the fact that the search radars being used could not differentiate between icebergs and fishing vessels which simply drift with the current. Coast Guard personnel reported that the radar mapping system effectively identified icebergs, growlers, and field ice, and differentiated between bergs and other stationary targets even in foggy weather.

Operation Features

Development of the *AN/APQ-55* was begun in 1955 under an Air Force contract, and completed and flight tested in only 16 months. The system is designed to map from either piloted or unmanned aircraft, at ground speeds of 200 to 800 knots, simultaneously recording strips of terrain, either 3 or 6 miles wide, on both sides of the aircraft. A modified version will map 10- or 20-mile widths. Another modification will allow mapping at ground speeds up to 2,200 knots.

Designed for low-altitude operation—1,000 to 5,000 feet—its light weight of 350 pounds, including antenna, makes possible its use in small aircraft without the removal of other normally carried equipment. Key factors in the small size and light weight achievement are the extensive utilization of transistors and a unique switching device that allows a single radar to look alternately from either side of the aircraft through side-looking back-to-back antennas.

Radar returns are displayed as a single-modulated trace on a cathode ray tube and recorded on film. TI developed and perfected a film-pulling mechanism that carries the film past the trace on the tube face proportional to the ground speed and altitude of the aircraft, thus producing a continuous, high-resolution film strip. The success of this recorder contributed greatly to the universal use of strip map recorders in subsequent reconnaissance systems. **EE**

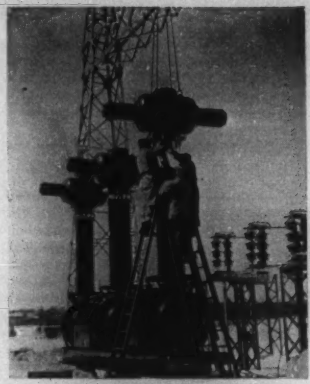
Air-Blast Breakers Installed in EHV Station

A 3-phase 115-kv air-blast circuit breaker has been installed at General Electric's Project EHV North Substation in less than 7 hours working time from rail siding to complete assembly on its foundation.

A crew of five men took 3 hours to unload, uncrate, and transport the breaker from flatcar to site. The trip included a 7-mile truck ride over rugged snow-banked country roads in near zero weather.

At the station site, workmen required only 3 hours to uncrate interrupter heads and place them on breaker support columns. High-voltage switchgear department engineer William Charles supervised installation. Two electricians did work in record time despite inexperience with this new-type breaker.

All three electrical connections necessary to complete the work took less than 1 hour despite extreme cold conditions. Although a 40-ton crane stationed at the Berkshire Hills site handled all necessary lifting, the construction engineers emphasized that a 20-ton unit would have been more than adequate to accomplish the job.



WORKMEN put bolts in place prior to lowering interrupter head into place on third unit of 115-kv air-blast circuit breaker installed in North Substation of Project EHV—General Electric's prototype super-voltage transmission system near Pittsfield, Mass. The job—from railroad flatcar to complete assembly on its foundation—took a 5-man crew less than 7 hours total working time. Breakers were built at GE's high-voltage switchgear department in Philadelphia, Pa.

Project EHV is General Electric's 4.5-mile prototype super-voltage transmission system now under construction near Pittsfield, Mass. **EE**

Foam Plastic Lens Aids Jet's Radar

A newly developed radar lens, made from a special foamed-plastic material, is giving "extra-sensitive perception" to the U.S. Air Force's newest fighter-bomber, it was reported recently.

Engineers at Republic Aviation Corporation say the lens is used in the airborne Doppler navigation system of the 1,400-mile-an-hour all-weather F-105D currently in production for the Tactical Air Command. The lens concentrates and amplifies the signals that actuate the Doppler unit. It is 17 inches in diameter and 5 inches thick, and is cast from epoxy foam made with a formula said to be lower in cost and higher in mechanical properties than similar materials on the market today.

Republic said it is marketing the material for use in radome linings and microwave encapsulations as well as radar lenses. The material has excellent machining characteristics, and can be foamed into complex contours and modified to suit any special electrical design, company engineers said. Other attributes cited as making

Future Meetings of Other Societies

ASME, Summer Annual Meeting & Aviation Conference, June 5-9, Statler Hilton Hotel, Dallas, Texas. L. S. Dennegar, The American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N.Y.

EEI, 28th Annual Convention, June 6-8, Atlantic City, N.J. Edison Electric Institute, 56th & Chestnut Sts., Philadelphia 39, Pa.

British Exhibition (including electrical and electronics industries), June 10-26, New York Coliseum, New York, N.Y. A. A. Schechter Associates, 551 Fifth Ave., New York 17, N.Y.

ANS, 6th Annual Meeting, June 12-15, Palmer House, Chicago, Ill. American Nuclear Society, John Crerar Library, 86 E. Randolph St., Chicago, Ill.

ASHRAE, 67th Annual Meeting, June 13-15, Vancouver, B.C., Canada. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 234 Fifth Ave., New York 1, N.Y.

Conference on Nuclear Geophysics of Interplanetary Matter, June 17-19, Northwestern University, Evanston, Ill. Air Force Office of Scientific Research, U. S. Air Force, Washington 25, D.C.

Institute of Radio Engineers

Spring Conference on Broadcast and TV Receivers, June 20-21, Graemere Hotel, Chicago, Ill.

Workshop on Solid-State Electronics, June 23-24, Purdue University, Lafayette, Ind.

4th National Convention on Military Electronics, June 27-29, Sheraton Park Hotel, Washington, D.C. IRE, 1 E. 79th St., New York 21, N.Y.

Indiana Society of Professional Engineers, 23rd Annual Convention, June 24-25, French Lick-Sheraton Hotel, G. W. Baldock, Indiana Society of Professional Engineers, 1224 N. Capitol Ave., Indianapolis, Ind.

ASTM, 62nd Annual Meeting, June 26-July 1, Chalfonte-Haddon Hall, Atlantic City, N.J. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Overseas

International Congress on Microwave Tubes, June 7-11, Munich, Germany. R. D. Paine, Jr., National Science Foundation, Washington 25, D.C.

International Conference on Large Electric Systems (CIGRE), 18th Convention June 15-25, 112 Boulevard Haussmann, Paris 8, France.

IFAC, 1st International Congress, June 27–July 27, Moscow. The Organizing Committee of the USSR National Committee for Automatic Control, Kalanchevskaja ul. 15-a, Moscow 1-53, USSR; American Express Co., 65 Broadway, New York 6, N.Y.

IEE, 3rd International Conference on Medical Electronics, July 21-27, Olympia, London, England. The Institution of Electrical Engineers, Savoy Place, London W.C.2.

UPADI, 7th Convention of the Pan American Federation of Engineering Societies, Sept. 12-16, Buenos Aires, Argentina. G. A. Hathaway, Engineers Joint Council, 29 W. 39th St., New York 18, N.Y.

5th International Instruments & Measurements Conference, Sept. 13-15, Stockholm, Sweden. Helge von Koch, Kungliga Tekniska Högskolan, Stockholm 70, Sweden.

8th Session of United Nations Scientific Committee on Effects of Atomic Radiation, Sept. 19-30, Geneva, Switzerland. United Nations Press Services, Office of Public Information, United Nations, New York, N.Y.

epoxy foam especially well suited for radar lenses are that it is lighter in weight and has a greater range of temperature stability (—67 to 250 F) than other commonly used materials, is completely noncombustible, has "very uniform dielectric constant" (good insulating characteristics), and low loss characteristics. The latter, it was explained, permits precision focusing of the radar beams with a minimum of microwave distortion. EE

"Brain" Pilots Plane Nonstop Across Country

A U. S. Air Force F-106 Delta Dart all-weather interceptor flew itself nonstop across the continent recently from California to Florida.

The 2,500-mile flight was the longest ever made by an interceptor aircraft without refueling. No attempt was made to set a speed mark, although the Convair-built F-106 holds the world's speed record of 1,525 mph, set in December 1959 at Edwards Air Force Base, Calif.

Maj. Frank Forsyth, the Air Materiel Command's Chief Acceptance Pilot for the F-106, took the Delta interceptor off the Palmdale (Calif.) runway at 8:48 a.m., PST. Minutes later, the F-106 picked up an electronic signal from the ground and Maj. Forsyth took his hands from the controls; the F-106 then flew itself to Jacksonville, Fla. Maj. Forsyth then took over control, turned and flew back to Tyndall Air Force Base, Fla. Flying time for the aircraft was 3 hours and 17 minutes to Jacksonville—for the pilot, about 5 minutes.

Key to the fully automatic flight was the aircraft's *MA-1* navigation and fire control system, built by the Hughes Aircraft Company. This system is designed to fly the interceptor through all phases of an intercept mission from shortly after takeoff to touchdown.

Before the F-106 took off, engineers preprogrammed its entire flight profile into the *MA-1* system's "Digitair" airborne digital computer. It included such information as route, altitude, and fuel available.

With this data and continuous range and bearing information flashed to the speeding aircraft by TACAN (tactical air navigation) stations across the country, the Hughes system automatically compared the jet's position to the prescribed route and supplied signals to the airborne flight control system. It automatically corrected heading and altitude.

Signals from each successive TACAN station automatically projected 400-mile-diameter maps on Maj. Forsyth's tactical situation display screen. These signals tuned the interceptor's radio receiver to the proper wave length and informed the computer which map was being displayed. Throughout the flight, the jet's precise position in relation to each control station, specific way points, mountains, air bases, and cities was indicated on the screen by a constantly moving symbol of the interceptor. The symbol was positioned by the computer, which in turn navigated by reference to the TACAN signals.

Maj. Forsyth took the Delta-winged interceptor off from Palmdale and held the controls to about 1,000 feet where the *MA-1* system picked up the first TACAN signal. Maj. Forsyth then switched over to automatic navigation mode, which piloted the supersonic jet to Jacksonville.

The F-106 was equipped with external fuel tanks for the initial leg of the journey. They were jettisoned over the Air Force firing range at Yuma, Ariz.

For combat, the F-106 is armed with the Hughes Falcon GAR-3 missile and the Douglas MB-1 atomic rocket. EE

Rugged TV Camera Needs No Auxiliary Housing

Development of a very rugged television camera, built to withstand weather, shock, vibration, noise, salt spray, dust, and other extremes of environment without an auxiliary protective housing has been announced by Dage Television Division of Thompson Ramo Wooldridge Inc., Michigan City, Ind.

Engineered to military requirements for use in all types and phases of missile and aircraft programs, this instrumentation camera is applicable for wide industrial usage in mines, chemical plants, oil refineries, powder plants, and other areas where a high performance, rugged camera is needed.

Designated the Dage Model *RGS-10* Ruggedized Television System, it consists of a camera and camera control capable of being operated up to 2,000 feet apart. Weighing only 15 pounds, the camera is 16 inches in length and 6⅞ inches in diameter, and is said to be the only camera known today which requires no additional housing to operate in all environments where the equipment conceivably could be used.

The system is totally transistorized, eliminating microphonics and erratic operation often caused by high acoustical noise levels, vibration, and other environmental circumstances. It employs modular construction, using plug-in transistorized printed circuit modules, each representing a particular function of the camera. This construction provides maximum reliability and ease of maintenance.

Unique in this equipment is the provision for the selection of manual or automatic light-level compensation. Another feature is the provision of noise reduction circuits which present a clean picture at low light levels. No additional equipment is required for pick-up of visual information.

A complete line of camera accessories, such as pan and tilt, lens turret, optical focus, and zoom lens are available with the equipment. Any type or combination of lens or lenses may be employed with the camera. Lenses, when employed with the camera, are an integral part of the camera configuration and are protected from all environments. Standard commercial lenses are normally utilized. If extremely hazardous conditions exist, optics covered by military specifications are employed.

Camera—The *RGS-10* Camera is completely transistorized, with the exception of the vidicon tube, and features EIA (Electronic Industries Association) synchronization, automatic light control over the range of 2,000:1, a built-in 4-lens turret, and horizontal resolution of more than 700 lines. It will operate at from —20 to +160 F; in noise levels of more than 185 db; and vibration to Mil-E-5272-B. The camera will operate with no limit on altitude, making it ideal for space chamber and flight test applications where conditions of low pressure are encountered.

Control Unit—The *RGS-10* Camera Control Unit is the completely transistorized companion to the *RGS-10* Camera, also featuring plug-in modules to facilitate change of function and service. The control unit is mounted on a 7- by 19-inch standard rack panel and weighs 15 pounds. Operational controls are: ON-OFF switch, automatic-manual target switch, and beam. Set up controls, such as pan and tilt, zoom lens, etc., and vhf connectors, provide peak-to-peak video composite or optimal modulated r-f.

Complete system of camera and control unit draws only 15 watts, 115 volts a-c, 50 to 60 cycles or 400 cycles (optional). EE

MAJ. Frank Forsyth examines "black boxes" comprising Hughes Aircraft Company's *MA-1* electronic control system which flew an Air Force Convair-built interceptor nonstop across the United States.

Super-Power Electron Gun Boosts Missile Radar Power

Scientists have developed an "electron gun" that removes one of the basic obstacles to extension of radar power and target detection range beyond present limits.

The new development, reported by Lindsey Anderson, research engineer at Sperry Gyroscope Company, can project an electron beam 5 times more powerful than earlier beam devices. The gun is being used to increase the power capabilities of large missile guidance radars and antimissile systems currently under construction for United States defense forces.

The new electron gun—which supersedes conventional filaments and cathodes, the primary power generating elements in high-power transmitter tubes—can project a beam of electrons that exceeds power-carrying capacity of high-tension power transmission lines. The beam developed by the gun is employed in multimillion-watt klystron tubes to generate the great quantities of microwave energy that form powerful radar beams for detection of fast moving objects in space.

The new gun can supply, if needed, electron beams of more than 200 million watts power and 1,000 amperes current to operate large klystron amplifiers and other super-power electron tubes. Initial tests of the new device in trial operations in super-power radars indicate that it may extend the operating life of large radar tubes by thousands of hours.

A basic factor in successful development of the Sperry gun is a special technique for creating an "ultra clean" operating environment inside the vacuum envelope of the electron tube. This special high-vacuum technique creates completely clean vacuums equivalent to a space environment 200 miles above the earth, where an average electron must travel 6 miles before encountering a single atom of matter. Such a vacuum is much less than one-billionth of normal atmospheric pressure. The "purity" of the vacuum is monitored by a sensitive mass spectrometer that can detect impurities as slight as one part in a trillion.

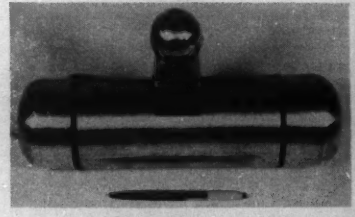
Also basic to the gun is a new type of rugged cathode described as an "extended interface coated cathode." This is a concave button of special nickel material, 1½ inches in diameter, which supports a thin coating of standard cathode oxide coating material. The cathode is the emitting source of electrons which the gun projects into a narrow high-density electron beam.

EE

Mobile Laboratory

IN SEPTEMBER 1958, for the first time in the annals of the electric power industry, an electrically transduced signal was transmitted from an energized 345-kv conductor to a recording oscillograph at ground potential. Through such experimental determinations by research engineers of Preformed Line Products Company, Cleveland, Ohio, it was learned that an electrically transduced signal could be transmitted feasibly from a high-voltage line and dynamic corona field to an isolated location. Thereupon it was decided to design and develop a mobile laboratory for the relatively short-term investigation and collection of valid vibration data from highly energized conductors. Result was the Preformed Line Patrol (*above, left*), a jeep vehicle equipped with 2-channel telemetering and recording apparatus. Electronic instrumentation equipment mounted in the patrol vehicle (*above, right*) is a radical innovation in remote-area transmission line evaluation. The mobile unit contains a short-range radio transmitter; receiving and discriminating equipment; a 2-channel direct writing Brush Instruments recorder; a communications radio, anemometers, and respective indicators.

◄ **Transducers are attached to the object(s) to be studied (the conductor, ground wire, tower structure, or hardware) with the Preformed Mark II Telemetering Transmitter attached in the immediate vicinity. Strain gauges used are Tatnall metal film type especially designed for this application. The strain gauge is applied with pressure sensitive cement.**



▲ **The Preformed Mark II Telemetering Transmitter is a single-channel, transistorized, battery-powered, FM/FM transmitter in a metallic casing. It meets requirements of low-power radiation, signal discrimination in the presence of corona and high magnetic field, weatherability, corona-free exterior at voltages up to 345-kv phase-to-phase, and ease of battery replacement. A 300-hour mercury battery is used.**

NBS Photo

EXPERIMENTAL corner-reflector antenna analyzed by the National Bureau of Standards. Length and width of reflecting surfaces, position of dipole, and aperture all can be varied to determine effect on gain. This assembly is located at the NBS Table Mesa field station, near the Bureau's Boulder (Colo.) Laboratories.

Design of Corner-Reflector Antennas

A DESIGN ANALYSIS of corner-reflector antennas has been carried out by the National Bureau of Standards (NBS) Boulder (Colo.) Laboratories under the sponsorship of the U.S. Air Force. The results of this evaluation[1] by H. V. Cottony and A. C. Wilson of the Bureau's Central Radio Propagation Laboratory provide comprehensive and detailed information on designing high-performance, economical corner reflectors.

Advantages

A corner-reflector antenna consists simply of two plane reflecting surfaces joined edge to edge to form a corner, which is usually parallel to the ground. The driven element is placed in the aperture between the two planes. This type of antenna has the advantages of high gain, broad frequency response, narrow beam width, low back radiation, low cost, and ease of construction.

Early experimental work in ionospheric scatter propagation stimulated interest in corner reflectors because they are particularly suitable for this mode of communication. Even though these antennas had been used prior to the new experimental scatter circuits, their performance was known only qualitatively. Therefore, as part of its propagation research program, NBS undertook an investigation of corner reflectors to determine how gain varies with changes in width and length of reflecting surfaces, angle of aperture, and position of driven element.

Experimental Equipment

The experimental corner-reflector antenna used for this investigation consisted of two lattice-type wooden frames, each 12.3 feet (5 wavelengths at 400 mc) wide by 12.3 feet long, supporting the reflecting surfaces. The reflectors were of overlapping strips of sheet aluminum fastened to the frames so that removal of one strip would subtract 0.2 wavelength from the surface. Width could be varied by trimming the lengths of the strips. The two frames were pivoted along the same axis, and it was possible for the angle of aperture to be varied from 20 to 180 degrees.

The driven element was a folded half-wave dipole. Its position could be varied from 0.07 to 2.5 wavelengths from the apex of the reflecting surfaces. The dipole's support also served as a balun to transform the impedance of the system to about 50 ohms. Fine adjustment, for an exact match to a 50-ohm line, was provided by a 2-stub tuning unit. Gain was measured at 400 mc by comparing the system with a known antenna.[2]

Although in practice collinear arrays of four and more dipoles are used in scatter antennas to obtain gains of over 20 db, the general performance can be predicted from an experimental system using only a single dipole. Because of this, only the single dipole was used for the measurements.

Gain Measurements

Results of the measurements indicate that minimum reflector width is 0.5 wavelength for the smallest usable value of gain. With an increase in width up to 2 wavelengths, gain increases. However, beyond this there is little or no increase in gain, and under some circumstances it may actually decrease.

For maximum gain, the dipole must be in one of several discreet positions—referred to as first, second, third, etc., in order of distance from the apex. The exact location of each position is a function of the aperture angle.

When the dipole is in the first position, gain increases monotonically as reflecting surface length increases. When the dipole is in the second or third positions, the same relation holds true generally, except for surface lengths less than 1.5 wavelengths. For these shorter lengths, the relation is not only too irregular for simple analysis but also does not provide the antenna designer with any useful data.

Maximum gain along the forward axis seems to be achieved with the dipole in the second position. In this case, the reflecting surface should be more than 2 wavelengths long and approximately 2 wavelengths wide.

Radiation Pattern

Ionospheric scatter antennas designed for the lowest portion of the vhf band should have especially low secondary lobes and minimal radiation to the rear as radiation in these undesired directions is likely to result in self-interference from multipath propagation. An important advantage of the corner reflector over other types of antennas is that it can be designed to have extremely low back radiation. The small amount that does occur results from diffraction around the edges and from penetration through small openings in the reflector surfaces.

Radiation patterns have been compiled

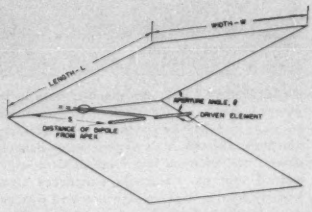


DIAGRAM of corner-reflector antenna.

for a variety of sizes of corner reflectors.[1] This material has been further summarized graphically so that beam widths and back radiation levels for any combination of surface lengths and widths are easily determined. EE

1. Radiation Pattern of Finite-Size Corner-Reflector Antennas, by A. C. Wilson and H. V. Cottony. IRE *Transactions* Ant. & Prop., vol. AP-8, no. 2, March 1960; for further technical information, see Gains of Finite-Size Corner-Reflector Antennas, by H. V. Cottony and A. C. Wilson. IRE *Transactions* Ant. & Prop. vol. AP-6, no. 4, October 1958.

2. Techniques for Accurate Measurement of Antenna Gain, by H. V. Cottony. NBS Circ. no. 598. Available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.; price, 15¢.

U.S. Army Signal Corps Celebrates Centennial Year

MARKING 100 years of Army signals on June 21, 1960, the U. S. Army Signal Corps celebrates a century of service to the Army and the Nation.

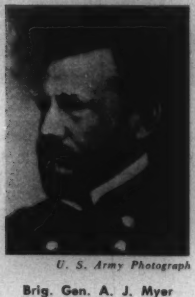
The founding of the Signal Corps as a separate branch is attributable to an Army surgeon, Major A. J. Myer, whose interest in helping the deaf led to a system of sign language between military outposts.

Authorized as Signal Officer of the Army on June 21, 1860, Major Myer filled a unique position as director of the first full-time signaling function of a national army.

From colored signaling flags to a communications satellite relaying voice and teletypewriter messages in outer space, it is a unique record; some capsule highlights follow:

1870: February 9, Signal Corps Weather Bureau

Congress assigned responsibility for forecasting storms on lakes and seacoasts to the War Department, which charged the Army Signal Corps with these new duties. Weather stations were erected throughout the nation, connected by telegraph lines, to provide meteorological data. This work continued until 1891, when all nonmilitary meteorology was transferred to the Department of Agriculture; in 1940 it was transferred to the Department of Commerce. Thus, the original organization and operations of the Signal Corps led ultimately to the present-day Weather Bureau.



U. S. Army Photograph

Brig. Gen. A. J. Myer
First Chief Signal Officer

1881 to 1884: First Army Arctic Exploration

Participating in a joint international effort to obtain meteorological data in Arctic areas, the Army Signal Corps dispatched one expedition to Point Barrow under command of Lt. P. H. Ray and another to Grinnell Sound under command of Lt. A. W. Greely. This was the first official peacetime enterprise in which the United States participated internationally.

1889: June, First Military Field Telephone Kit

A combination of the Bell telephone and a telegraph instrument, the first military field telephone kit was developed by the Army Signal Corps.

1908: August 4, First Military Dirigible

A powered gas-filled dirigible was first tested by the Army Signal Corps at Fort Myer, Va., piloted by the builders, Glenn Curtiss and Thomas Baldwin. It was accepted by the Aeronautical Board of the Signal Corps, and designated *Dirigible No. 1*. Subsequently, more than a dozen airships of this type were procured by the Signal Corps for training purposes.

1910: September 18, First Wire-Wireless Communication

Over a single twisted-pair wire telephone circuit between the Signal Corps Laboratory at the National Bureau of Standards and a small laboratory on Pennsylvania Avenue in Washington, D.C., two separate telephone conversations were carried simultaneously.

1937: May 18, First American Radar

An experimental model of the first Army radar set, designed and developed by the Signal Corps, was successfully demonstrated at Fort Monmouth, N.J. Known as the *SCR-268*, it was used to detect and locate aircraft and to direct searchlight beams for antiaircraft batteries. It was the progenitor of many Army radar sets developed by the Army Signal Corps. Chief among these were the *SCR-270* and *SCR-271* long-range aircraft detection radar sets.

The first overseas installation of radar sets—*SCR-270* and *SCR-271*—was at Fort Sherman in the Canal Zone, early in 1940.

The first *SCR-268* radar set was installed in Iceland during September 1941. Seven of these sets were installed in gun battery positions in Panama by October 1941.

1945: April 28, Fastest Message Around the World

Through facilities of the Army Signal Corps, a 9-word radioteletype message was transmitted around the world in 9.5 seconds to set a new record for speed. The previous record of 3.5 minutes was set in May 1944.

1946: January 10, First Radar Contact with the Moon

Using a modified *SCR-271* long-range radar set, engineers of the Army Signal Corps at Belmar, N.J., succeeded in making radio contact with the moon. This was known as Project Diana.

1957: December 5, First Operational Electronic System for Co-ordinating and Controlling Antiaircraft Missile Batteries

The first operational electronic system—the MISSILE MASTER—for controlling and co-ordinating the use of NIKE and HAWK missile batteries was placed in action defending the Washington-Baltimore area. Developed for the Army by The Martin Company working with the Army Signal Corps, the system was received by a group of Department of the Army representatives headed by the Secretary of the Army and turned over to the U. S. Army Air Defense Command at its installation at Fort George G. Meade, Md. The system collects information on the location of aircraft and their identity, presents this information on electronic displays, and distributes this data to the missile-firing batteries.

1958: December 18, First Satellite Communications Relay To Relay Voice and Teletypewriter Signals Actively Through Space

The Atlas was successfully launched and placed in orbit by the Air Force carrying an Army communications package that became the first radio communications relay in outer space. Under the direction of the Advanced Research Projects Agency, the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, developed with industry the space communications relay and the associated ground stations. The achievement—called Project SCORE—marked the first time that human intelligence was actively relayed through voice and teletypewriter signals by communications equipment in outer space. A goodwill message by President Eisenhower stressing America's wish for "Peach on Earth" was the first voice to be transmitted in space. Contributing firms who worked with Army scientists were Radio Corporation of America, Eagle-Pitcher Lead Company, Porter Bromfield, Convair-Astronautics Division of General Dynamics, Radiation, Inc., and R. F. Laboratories.

U. S. Army Photograph

Maj. Gen. R. T. Nelson
Present Chief Signal Officer

(A group of pictorial highlights appear on the pages which follow.)

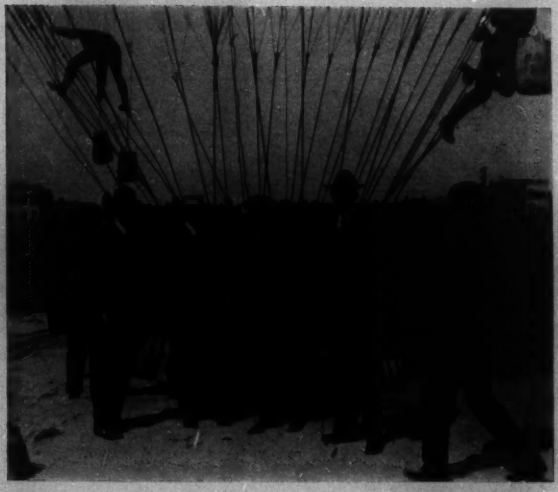
◄ Group of Signal Corps Officers at camp instructions.

U. S. Army Photographs

United States Army Signal Corps

▲ 1881-1883, Alaska. U. S. Signal Station, main building (front view), Point Barrow Expedition.

► 1896, Manila, Fort Malate. Signaling for reserves to advance after retreat of the Spanish.



◄ 1908, Washington, D. C. Signal Corps balloon ascension at Gas House Field, (*left to right*): Lt. F. P. Lahm, Capt. Chandler, Capt. R. O. Van Horn, and Lt. T. E. Selfridge, who made the ascent.

▼ 1908, Fort Myer, Va. U. S. Army Dirigible No. 1.

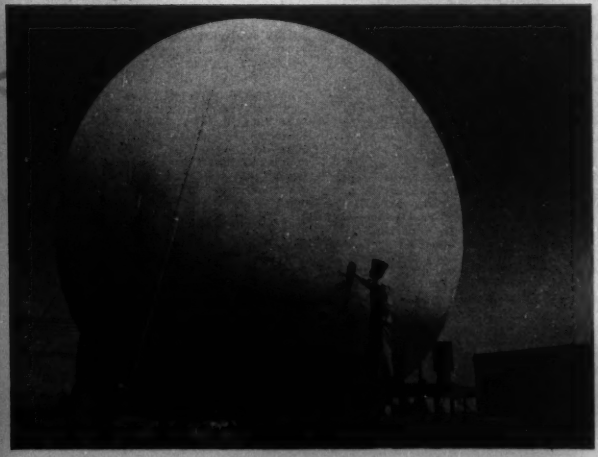
▲ 1918, Mareuilen-Dole, France. Pvt. E. B. Schoedsack with camouflaged camera, photographing among the ruins.

► 1944, European Theater of Operations. Working in snow, Cpl. Arthur Marino (Beeville, Texas) U. S. First Army, traces a broken field wire line for splicing.

▲ 1951, Korea. Cpl. Elmer Soprano of Sayre, Pa., a member of the First Platoon, Company A, 4th Signal Battalion, on a line pole, leans dangerously over a cliff to fasten a jumper as the group rehabilitates lines from Tanyang to Chechon.

Centennial Year 1860-1960

U. S. Army Photographs



▲ 1957, Fort Meade, Md. The height finder radar scans the skies at the U. S. Army Missile Master installation.

◄ 1958, Fullerton, Calif. A plastic balloon, resting on mobile trailer bed, forms housing for antenna of FRESCANAR, electronic-beam radar system. The antenna operates from within inflated balloon, protected from snow, ice, and wind. EE

Atomic Research Center Being Built Near Vienna

A nuclear research reactor will go critical on September 30 at the Austrian Atomic Energy Research Center now being completed at Seibersdorf, on the outskirts of Vienna, Austria. The announcement was made recently by Dr. M. J. Higatsberger, executive director of the Austrian Atomic Research Organization.

Known as ASTRA

The reactor, known as "Adapted Swimming-Pool Tank Reactor Austria," (ASTRA) is designed and engineered by the American Machine & Foundry Company (AMF) of New York. AMF Chairman Morehead Patterson described ASTRA as a 5,000-expansible to 2,000-kw pool tank type reactor.

Scheduled to go critical well in time for the next General Conference in Vienna of the International Atomic Energy Agency, which will utilize and participate in the Austrian organization's research center at Seibersdorf, the reactor project has been rushed to completion since first contracted with AMF in May 1958. Dr. Higatsberger pointed out that the project will be fully operational in less than 2½ years.

The fuel elements have been ordered from M & C Nuclear, a division of Metals & Controls, Inc. of Attleboro, Mass.

Austria's advance into atomic energy research has not been impelled by a need for new sources of industrial energy, Dr. Higatsberger stated. The nation's hydroelectric resources last year enabled the Austrians to produce 15 billion kwh of electricity. One consequence is that the Austrian grid is now Europe's largest exporter of electricity—some 2 billion kwh in 1959. When fully tapped, it is estimated that Austria's resources will permit an annual production of 43 billion kwh. In addition, the country has abundant reserves of coal, oil, and natural gas.

Peaceful Development Stressed

Astride the Free World's border with the Communist Bloc, Austria intends the Seibersdorf program to demonstrate the values of the peaceful development of atomic energy for all mankind, Dr. Higatsberger said. Working with all segments of Austrian industry, the Center will explore the use of active isotopes; the influence of radiation on radiation-induced chemical reactions such as polymerization, vulcanization, halogenation, etc.; and mineral oil cracking processes as influenced by radiation. In the field of medical research, projects will include work in pharmacological utilization of radioactive isotopes.

The Seibersdorf Center, Dr. Higatsberger noted, will include laboratories for research into atomic energy's application in the fields of physics, electronics, chemistry, metallurgy, medicine, biology, and agriculture. In addition, the center will provide all necessary auxiliary facilities, including workshops, storage buildings, administration headquarters, central power station, and a lecture hall. Total costs for the installation will come to roughly $6 million.

Austria and the United States, noted Dr. Higatsberger, have concluded a bilateral agreement under which the U. S. Government will extend technical advice to Austria in the peaceful atomic energy field. A grant of $350,000 will be contributed by the U. S. Atomic Energy Commission toward the erection of the research reactor. Otherwise, the Center is completely financed by Austria.

EE

REACTOR BUILDING at the Austrian Atomic Energy Research Center, which is now being completed at Seibersdorf, on the outskirts of Vienna. ASTRA, a 5-mw research reactor is being supplied by AMF Atomics.

NEW BOOKS

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ELECTROMAGNETIC FIELDS, ENERGY, AND FORCES. By R. M. Fano and others. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., 1960. 520 pages, 6 by 9¼ inches, bound. $12. Emphasizing synthesis as opposed to analysis of fields, this book develops a consistent macroscopic theory of electromagnetism, including that of moving bodies. The process of electromechanical energy conversion is covered, and a power-series technique for analyzing quasi-static fields and quasi-stationary systems is introduced. Appendices include material on the 4-unit mks system of units used, and a 4-dimensional relativistic formulation of macroscopic electrodynamics.

ELECTRICAL ENGINEERING FOR PROFESSIONAL ENGINEERS' EXAMINATIONS. By J. D. Constance. McGraw-Hill Book Company, 330 W. 42nd St., New York, 36, N. Y., 1959. 448 pages, 5½ by 8¼ inches, bound. $9.50. This compilation of problems from past examinations along with sufficient background material enable the reader to understand the basic theory behind the problems. Each problem is followed by numerical or essay answers of the type expected by the boards of examiners. Appendices provide additional problems in the various fields covered, and a list of references for further study is included.

CYBERNETICS AND MANAGEMENT. By Stafford Beer. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., 1959. 214 pages, 5½ by 8¼ inches, bound. $4.50. This account of cybernetics, written with management specifically in mind, presents the basic principles of the nature of control and explicates the main concepts with a minimum of mathematics and scientific detail. This book brings together theories on control from logic, biophysics, and analog theory in such a way that the information from these diversified fields can be a scientific tool for understanding and organizing systems and machines useful in the handling of men and situations.

ELECTROMAGNETISM AND RELATIVITY. By E. G. Cullwick. Second edition. Longmans, Green and Co., Inc., 119 W. 40th Street, New York 18, N. Y., 1959. 291 pages, 5½ by 9 inches, bound. $12.50. This treatment stresses the fundamentals of electromagnetic physics within the relativistic framework for advanced students of physics and electrical engineers. It is particularly concerned with moving bodies and electromagnetic induction, and includes a detailed discussion of the Special Theory of Relativity and its application to electromagnetism, as well as the original elemental theory. The author proposes a new law of magnetic energy to throw a new light on the theory of currents in superconductors. In this edition, the clock paradox has been revised, and new points have been added or clarified in the equivalence of magnetic and electron-kinetic energy for steady and quasi-steady currents.

CATHODIC PROTECTION. By J. H. Morgan. The Macmillan Company, 60 Fifth Ave., New York 11, N. Y., 1960. 325 pages, 6¼ by 10 inches, bound. $12. The technique of the electrical method of corrosion prevention, rather than the electrochemistry of the interface, is the subject of this English textbook on cathodic projection. The first part of the book is devoted to the methods and the factors involved in this method of prevention; the second part considers the procedures in achieving protection in a variety of structures, such as buried pipes and tanks, structures in sea water, structures containing interference corrosion. Instruments for cathodic protection and the economics of this method are dealt with in the last chapters of the book.

ASTM STANDARDS ON COPPER AND COPPER ALLOYS. Published by the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., 1959. 704 pages, 6¼ by 9¼ inches, bound. $7.50. Included in this special compilation is information on nonferrous materials for electric conductors and for use in copper-alloy products.

Newport News rack rakes . . . minimum-manpower way to keep water intakes free of debris

Newport News mechanical rack rakes are power-operated rakes for cleaning trash racks at water intakes, including those at hydro-electric plants, steam plants, pumping stations, and similar installations throughout this country and abroad. Under ordinary conditions, one man per shift keeps racks clean for a dozen bays.

Operate in channel guides for maximum cleaning action

A Newport News rake *won't ride over trash* nor will its teeth drop the debris, because the rake operates in channel guides for positive action. Special teeth are available for cleaning racks of filamentous algae, seaweed, etc.

The Newport News mechanical rack rake has been built to operate in bays from 5 feet 6 inches wide to 28 feet 6 inches in width. Forebay design determines the maximum width for a single rake. In the case of a very wide bay, intermediate guides are sometimes used to reduce the length of the rake. There are many typical installation arrangements to fit your needs. Newport News engineers are prepared to individualize these designs for you.

If you have a debris problem, write for a copy of THE NEWPORT NEWS MECHANICAL RACK RAKE, an illustrated booklet describing the installation, operation, and advantages of a Newport News rake.

Engineers . . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News
Shipbuilding and Dry Dock Company
Newport News, Virginia

GTC

UNITIZED
COMMUNICATION
EQUIPMENT for
POWER and INDUSTRY

Effective!
Reliable!
Economical!

1 Highly effective in extremes of ambient noise and temperature.
2 Plug-in units provide ease of installation, expansion and maintenance.
3 Transistors and rugged, industrial type components used throughout.
4 Central control cabinet, costly engineering and fabrication eliminated.

Wherever a highly dependable, voice communication system for use in high noise level areas is needed—you'll find GAI-TRONICS specified by name.

GTC is extremely flexible in application. Write today for a copy of our completely illustrated, descriptive booklet and name of nearest representative.

GAI-TRONICS
CORPORATION
Dept. B
READING, PENNA.

GAI
Equipped for Life

A SUBSIDIARY OF
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSTRUCTORS

Trade Literature...

"The All-Purpose Copymaker" . . .

A 16-page booklet, titled "The All-Purpose Copymaker," explains to potential users the time and cost savings derived from photocopy use by small and large companies alike. Each model in the company's Auto-Stat line of photocopiers is described in detail, along with the type of office it is designed to serve. Regardless of price range, each unit is versatile enough to copy anything written, printed, photographed, or drawn from any color paper or ink. *American Photocopy Equipment Co., 2100 W. Dempster St., Evanston, Ill.*

Precision Potentiometer Selector Chart . . .

This chart, measuring 24 by 30 inches, is suitable for wall mounting. It contains complete and easily read specifications including electrical, mechanical, mounting, special features, and environmental information on 37 standard models of single and multiturn precision potentiometers. *Spectrol Electronics Corp. 1710 South Del Mar Ave., San Gabriel, Calif.*

Building Wire Bulletin . . .

A "Synthinol *901* Building Wire," is now available from Rome Cable Division of Alcoa. Synthinol, a polyvinyl chloride compound, and its applications in wiring are discussed at length. The illustrated bulletin describes physical properties and electrical characteristics of Synthinol and the many industry specifications it meets. Advertising Department, *Rome Cable Division of Alcoa, Rome, N.Y.*

"T" Retainer Bearing Engineering Data . . .

A 4-page engineering data sheet on the "T" retainer bearing has been made available. The "T" retainer combines the high-speed qualities of laminated phenolic and the high strength of aluminum alloy. Operating temperatures range up to 300 F for continuous operation, and 350 F for short periods. Maximum speeds of up to 110,000 rpm are permissible with grease lubrication under moderate loads and moderate temperatures. For longer life at high speeds, oil mist or spray lubrication is usually required. Applications include high-speed alternator, turbine- and gear-driven accessories and power units for aircraft and missiles; motors, generators, air- or electric-driven power tools; machine-tool spindles, gyro rotors, and other applications requiring long life at high speeds. *The Barden Corp., 200 Park Ave., Danbury, Conn.*

"Coatings for Vacuum Metallizing" . . .

A 45-page booklet, "Coatings for Vacuum Metallizing," describes in detail the application and use of vacuum metallizing coatings which may be applied by spraying, dipping, and flow coating to thermoplastics, thermosetting plastics, metals, and glass. Base coats for use before metallizing as well as top coats and back-up coats for use after metallizing are discussed along with other helpful information on the metallizing operation. *Bee Chemical Co., Logo Division, 12933 S. Stony Island Ave., Chicago 33, Ill.*

Biddle Instruments . . .

This digest is published every 2 years describing every major line the company makes or sells. Those desiring complete information on specific instruments can obtain carefully detailed literature on any of the subjects covered by sending in business cards inserted in the digest. Write for bulletin 19-60-7, Biddle Instruments, *James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

Stock Catalog . . .

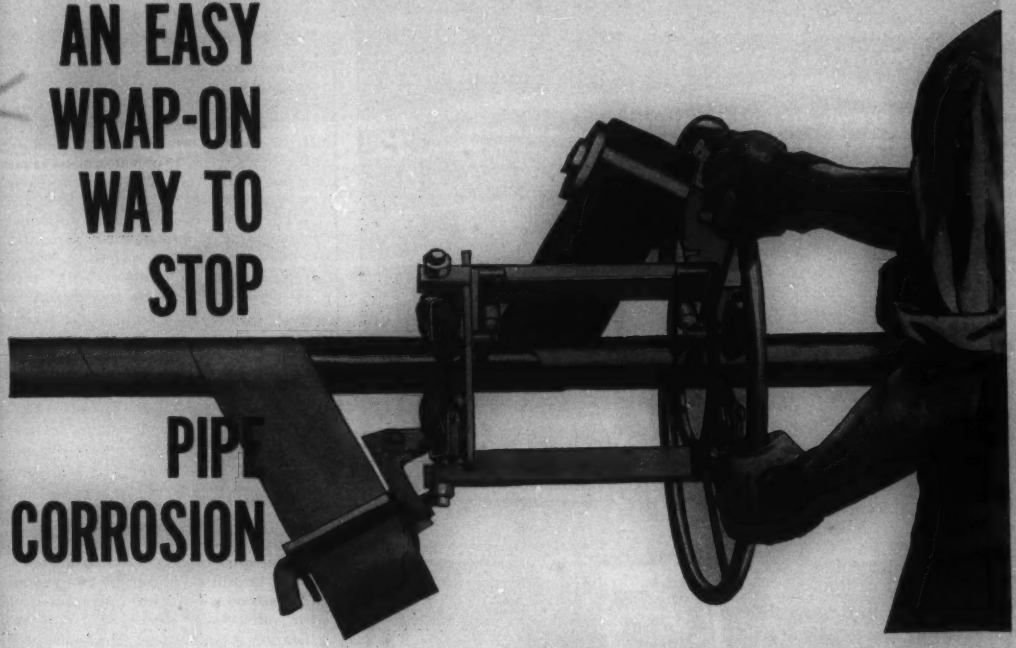
The very latest prices, listings, and data are carried in a new issue of the Ohmite Manufacturing Co. 32-page 2-color stock catalog no. 30A. This catalog lists an increased selection in the company's long-established products as well as in some of its newer products. *Ohmite Manufacturing Co., 3695 Howard St., Skokie, Ill.*

Wave Guide Seal Conversion Chart . . .

A wave guide conversion chart for flange seals shows all wave band series and various seals to fit standard flanges. Also included are dimensions and other pertinent data useful for checking materials, sizes, etc. *Parker Seal Co., 10567 Jefferson Blvd., Culver City, Calif.*

(Continued on page 44A)

AN EASY WRAP-ON WAY TO STOP PIPE CORROSION



The new CORR-PREV Pipe Coating Team comes in easy to handle tape form. It goes on pipe faster and lasts longer than corrosion-proof paints. It's cleaner and simpler to apply, too, than hot tar coats. And most important, this new CORR-PREV Team offers all the cost-cutting, pipe-saving advantages of *polyethylene* tape.

With CHASEWRAP Abrasion-Resistant Overwrap and Chasekote polyethylene tape, you get the easiest and best pipe protection at *lowest applied cost!* There's no heating, drying, clean-up or shut-down time. Each roll is factory-uniform in thickness and quality. And all coating materials — including rental of high-speed applicators — are available from one reliable source. Want samples? Specs? Prices? Write **CHASE & SONS, INC., 26 Spruce St., North Quincy, Mass.**

Chasekote*

Pressure-Sensitive Polyethylene Tape has an extra-heavy adhesive mass that clings to clean pipe on contact . . . makes a perfect, permanent bond that rustproofs, waterproofs and insulates pipe against all types of corrosion.

Chasewrap*

Protective Overwrap is a tough, wrinkle-free outerwrap that shields against abrasion, wear, and physical damage to the tape. Wraps simultaneously with the tape. Superior to rag and felt wraps, yet far lower in cost.

**Trade name of Chase & Sons, Inc., long-famous for protective and insulating tapes for electrical wire and cable*

Refineries & Gathering Systems

Public Building Lines

Oil & Gas Transmission Lines

Highway and Airport Conduit & Pipe

Utility Distribution Systems

Chemical & Industrial Plant Piping

FOR YOUR ELECTRICAL INSULATION PROBLEMS SPECIFY CHASE FRICTION, PLASTIC, RUBBER, NEOPRENE AND BUTYL TAPES

Trade Literature

(Continued from page 42A)

Some Plain Talk About Fuel Cells . . .

This 12-page booklet discusses basic facts about fuel cells including how they work, problem areas, various types of fuel cells under development, special features of the new ion-membrane fuel cell, technical performance data, and application information. Photographs, graphs, schematic drawings, and diagrams illustrate the text. *General Electric Co., Schenectady 5, N. Y.*

Carbon and Graphite Products Brochure . . .

The brochure includes detailed data on the mechanical, chemical, and electrical properties of carbon and graphite. Among specific applications discussed are high-temperature rocket parts; boats, crucibles, molds, and jigs; electronic power components; heaters; production applications; and boronated graphite for control and shielding purposes in nuclear operations and for other uses where oxidation resistance is important. Recommended techniques for machining carbon and graphite parts are outlined. Charts, graphs, dimensional diagrams and illustrations are included. Write: Merle Lecker, *Speer Carbon Co., St. Marys, Pa.*

Guide to Silicones and their Uses . . .

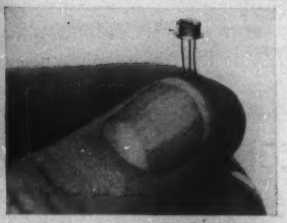
An up-to-the-minute summary of the forms, properties, and applications of Dow Corning silicones is contained in this 16-page brochure. Silicone products reviewed range from adhesives to release agents, laminating resins to rubber compounds, and electrical insulation to water repellents. *Dow Corning Corp., Midland, Mich.*

Speed Recorder Bulletin . . .

Bulletin 260 describes and illustrates up-to-date applications of the Esterline-Angus Co. speed recording system. More specifically, this bulletin covers the use of speed recorders in newspaper production, highway surface evaluation, paper processing, and brake research. It also includes a complete description of the use of speed relays to protect belt conveyors. *The Esterline-Angus Co., Dept. 26, Box 596, Indianapolis 6, Ind.*

(Continued on page 46A)

Opportunities in Development



New developments in Esaki Diode technology at IBM

The Esaki Diode at left was made experimentally.

Soon after the original discovery of the Esaki Diode, I engineers and scientists began a thorough investigat of its properties. As a result of this investigation, IBM evolved new techniques to improve some of its most portant characteristics. A stage of development has b reached where germanium Esaki Diodes can be made w peak-to-valley ratios averaging between 14 and 15 t and with peak currents that can be controlled within

Looking at All Aspects

At IBM, the Esaki Diode is being examined from m viewpoints. Physicists and mathematicians are study the theoretical foundations of its behavior. Other sc tists and engineers are probing its electrical characte tics. Still others are refining techniques for its construct

It takes the varied skills of many engineers and scien to advance the state of new and complex technology also takes the inherent progressive spirit of an organ tion interested in making these advances.

Careers in Frontier Fields

Solid state studies may not be your primary interest. may have specialized in other areas of engineering, one of the sciences. But whatever your goals or your b ground, you'll find opportunity for fascinating wor frontier fields at IBM's expanding research and deve ment laboratories.

If you have a degree in engineering, mathematics, or of the sciences—plus experience in your field—w briefly outlining your qualifications, to:

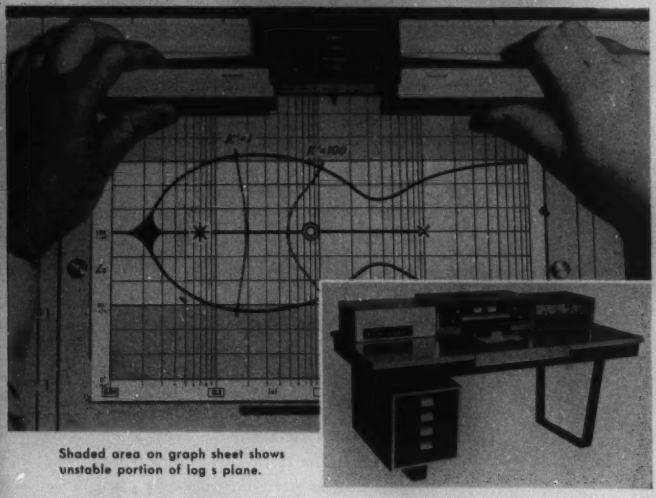
Manager of Technical Employment
IBM Corporation, Dept. 550R
590 Madison Avenue, New York 22, N. Y.

IBM INTERNATIONAL BUSINESS MACHINES CORPORA

new approach to system design problems

- Solves differential equations by ROOT LOCUS plots.
- Provides BODE phase and gain plots from system poles and zeros.
- Synthesizes compensation networks.
- Evaluates residues.
- Factors polynomials.
- Analyzes sampled data systems.
- Solves non-linear problems involving hysteresis or saturation by the describing function technique.
- Designs process control systems.
- Derives process transfer functions from power density spectra.
- Uses rapid, logical pole-zero programming.

esiac



Shaded area on graph sheet shows unstable portion of log s plane.

A complete analog computer that increases system design productivity more than five fold at a net price less than the yearly salary of a design engineer. The Esiac rapidly solves generalized system equations expressed in the following forms:

$$F = \pm K s^{n_0} (s - s_1)^{n_1} (s - s_2)^{n_2} (s - s_3)^{n_3} \ldots$$

or

$$F = \pm K s^{n_0} \left(1 - \frac{s}{s_1}\right)^{n_1} \left(1 - \frac{s}{s_2}\right)^{n_2} \left(1 - \frac{s}{s_3}\right)^{n_3} \ldots$$

Write for descriptive engineering bulletins, Esiac solutions to system design problems, or an Esiac demonstration in your plant.

esi®

SEND FOR DESCRIPTIVE LITERATURE
See it demonstrated
1960 WESCON, NEC
and ISA SHOWS

Electro Scientific Industries
7524 S.W. MACADAM • PORTLAND 19, OREGON
CHerry 6-3331

formerly ELECTRO-MEASUREMENTS, INC.

ESI has outstanding opportunities for design and applications engineers. Call or write Mr. Davis.

Trade Literature

(Continued from page 44A)

"Quality Assurance for Printed Wiring" . . .

A complete quality assurance system for the manufacture of printed circuits is described in an illustrated technical bulletin recently published by Photocircuits Corp. Covered in detail are quality control procedures in accordance with military specifications MIL-Q-9858 and MIL-STD-105. Bulletin number P-10, "Quality Assurance for Printed Wiring," is available on request from Department 1700, *Photocircuits Corp., 31 Sea Cliff Ave., Glen Cove, N. Y.*

"Conversion Factors" . . .

This 21-page pocket-size compilation of multiplication factors converts fundamental electrical and magnetic units. Over 800 conversion factors will provide practicing engineers with an easy-to-use working tool of information which is normally scattered throughout technical literature. The booklet, Circular 1956, may be obtained without cost by writing attention, Director of Control Equipment Sales, *Automatic Electric, Northlake, Ill.*

Carbon Dioxide and Its Uses . . .

A 24-page booklet on carbon dioxide and its value to industry covers the history, principal applications, properties, manufacture, supply, and distribution of carbon dioxide in gaseous, liquid, and solid form. This booklet contains data necessary for readers to gain a clear understanding of how this versatile chemical can be used in industry today. Specify form ADPC 41, *Pure Carbonic Co., a division of Air Reduction Co., Inc., 150 East 42nd St., New York 17, N. Y.*

Nontechnical Booklet on Molybdenum Products . . .

A nontechnical, descriptive booklet on Climelt molybdenum products has been published for those executives, purchasing agents, and others with a general interest in the unique combination of properties found in these materials. The 24-page booklet, "Climelt Molybdenum and Molybdenum-Base Alloys," gives full details on the various sizes, forms, conditions of use, tolerances, weights, and methods of identification of Climelt products now available for commercial use. *Climax Molybdenum Co., 1270 Ave. of the Americas, New York, 20, N. Y.*

(Continued on page 47A)

Trade Literature

(Continued from page 46A)

Logarithmic Converter Application Note . . .

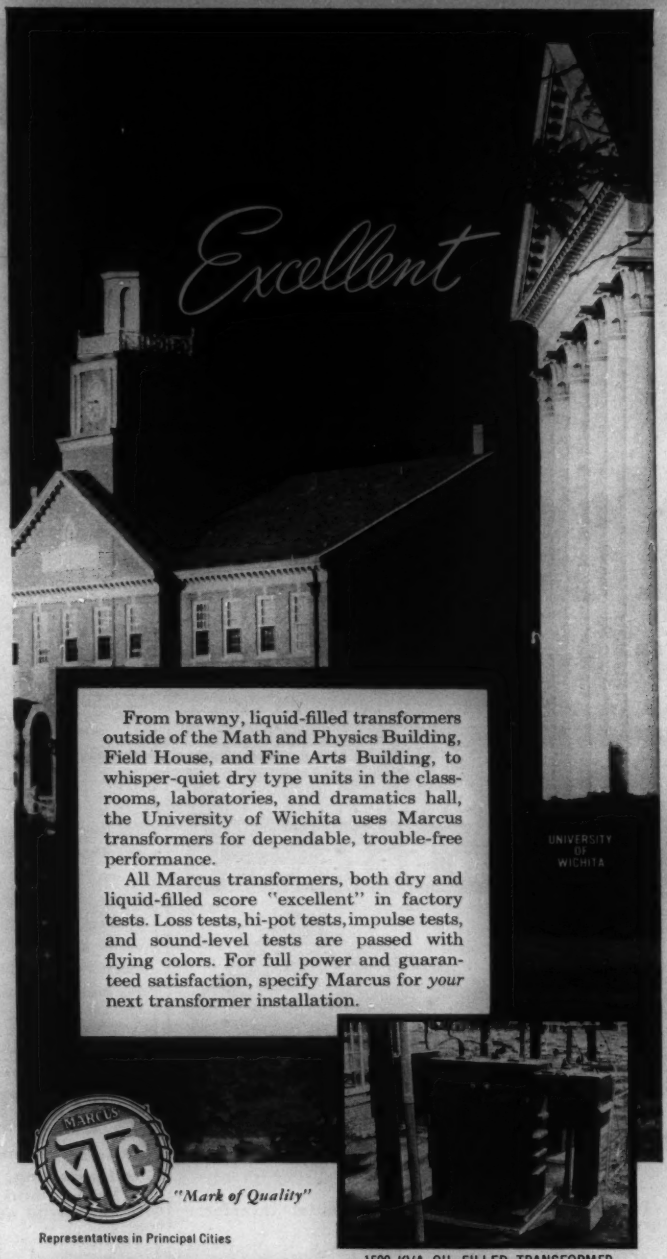
A 4-page application note describing the use of the model 60B logarithmic converter as a computing element is now available from the F. L. Moseley Co. The note explains how the 60B, when used in pairs and with a suitable read-out device, can readily Any read-out device may be used, provided the complete load impedance perform multiplication and division. agrees with the values presented in the application note's diagrams and tables. The application note, AN-101, may be obtained by writing the *F. L. Moseley Co., 409 N. Fair Oaks Ave., Pasadena, Calif.*

Refrigeration Systems for Cryogenic Electronics . . .

A variety of miniature and compact refrigeration systems for cooling electronic devices to temperatures ranging from 3.5 to 200 K is described in a new brochure. To meet the expanding needs of the electronics industry for refrigeration equipment to operate infrared detectors, masers, irasers, parametric amplifiers, and for transistor and superconductor applications, a wide variety of matched components for refrigeration systems has been developed and manufactured. Operational systems are now available for airborne, land-based, and laboratory applications. *Air Products, Inc., P.O. Box 538, Allentown, Pa.*

Color Card of Industrial Finishes . . .

Shown are approximately 64 shades available in lacquers, synthetics, vinyls, and specialty finishes in a complete scale of lusters at six levels, whereby selective determination of sheen is readily made. Finishes included are wrinkles, metallics, pearlized Hammermark, Uniloids, metallic Hammermark, Golden "Veil" Lacquer, Multakolor, stain, crystal lacquers, crackle lacquers, and clear lacquers. United has included in the swatches 1960 and 1961 *House & Garden* magazine color shades, as requested by many industrial firms. *United Lacquer Manufacturing Corp., 1001 W. Elizabeth Ave., Linden, N. J.*



From brawny, liquid-filled transformers outside of the Math and Physics Building, Field House, and Fine Arts Building, to whisper-quiet dry type units in the classrooms, laboratories, and dramatics hall, the University of Wichita uses Marcus transformers for dependable, trouble-free performance.

All Marcus transformers, both dry and liquid-filled score "excellent" in factory tests. Loss tests, hi-pot tests, impulse tests, and sound-level tests are passed with flying colors. For full power and guaranteed satisfaction, specify Marcus for *your* next transformer installation.

MARCUS MTC "Mark of Quality"

Representatives in Principal Cities

1500 KVA OIL FILLED TRANSFORMER

MARCUS TRANSFORMER CO., Inc.

RAHWAY, NEW JERSEY

A COMPLETE LINE OF DRY TYPE AND LIQUID-FILLED TRANSFORMERS THRU 5000 KVA

The Red (H) Line
of
QUALITY TRANSFORMERS

Standard Dry Type, Control transformers designed and manufactured for dependability and long life to the highest standards of workmanship. Also special purpose types made to the most exacting specs. Send us your requests for quote.

FREE BROCHURE AND OTHER VALUABLE DATA TO ENGINEERS, ON YOUR LETTERHEAD.

HINDLE TRANSFORMER CO., INC.
FLEMINGTON, N. J.

Copaco
CLASS A
ELECTRICAL INSULATING PAPER

- Dielectric strength — 300 volts per mile
- Tensile strength — 13 — 16,000 lbs./Sq. In.
- Density: 1.30 — 1.35
- Thickness from .004" to .030"
- 100% rag stock paper
- No sizing or fillers used.

"Glazed roll" finish — others available.
Can be combined with other materials.
Available in rolls, sheets or coils.

High Performance Electrical Insulators

COPACO — Highest grade 100% rag insulation paper
COPAREX — Economical grade 100% rag insulation paper
COPALAM — Class B asbestos — glass laminate insulation material

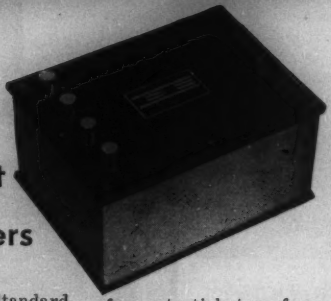
Write for free samples, literature and name of nearest Cottrell representative.

COTTRELL Paper Company, Inc.
88 Purchase St. Fall River, Mass.

420-9

You can rely upon
KNOPP Standard
Burden Sets...

when
testing
instrument
transformers



The Knopp Standard Burden Sets offer burdens of reliable accuracy and stability and burdens that possess a freedom from stray fields and harmonics.

Burden Sets are now available for ASA standard burdens for current transformers from B-0.1 through B-8. and for ASA burdens W, X, Y, and Z for potential transformers.

Accuracy of resistance and inductance values within 1.0 percent.

For full details about the Knopp Standard Burden Sets, write today.

KNOPP INC.
Dept. A-15, 1307 66th St.,
Oakland 8, Calif.

SALES ENGINEERS

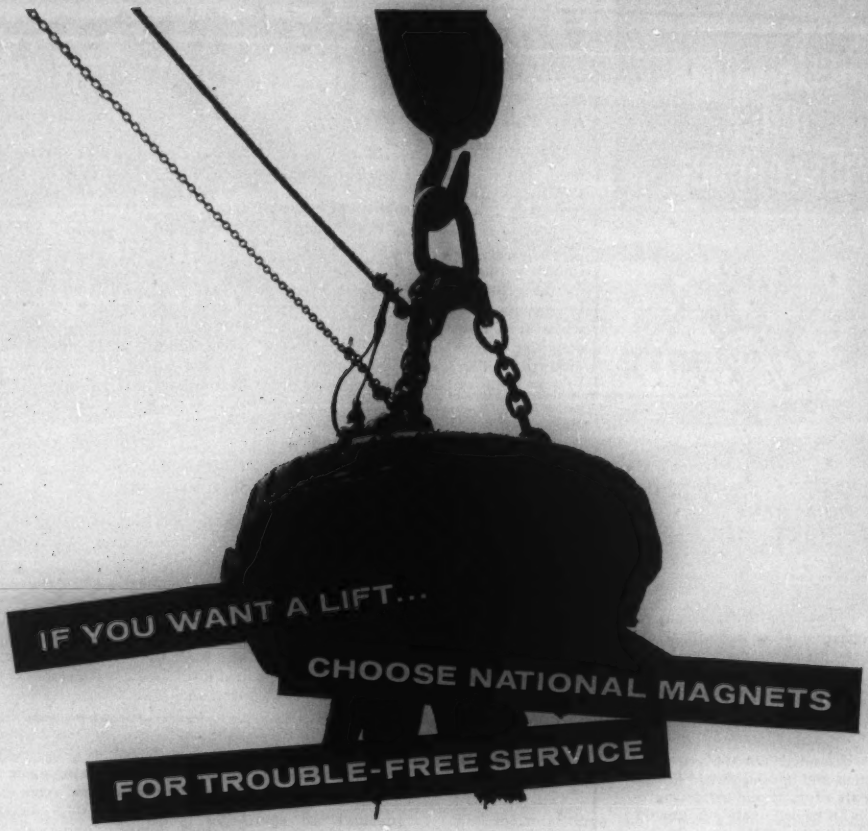
We are placing on the market several new products including recording and controlling instruments and require Sales Engineers for our Houston, St. Louis, Chicago, Detroit, and Cleveland districts. Prefer Electrical, Mechanical, or Chemical Engineers. Can offer excellent opportunities for qualified men. Successful candidates will be given a factory course at Waterbury before assignment to one of the above districts. Write Mr. H. E. Beane, Vice President, The Bristol Company, Waterbury 20, Connecticut.

ELECTRONICS ENGINEER

- **To be key member of small integrated group**
- **Interesting, challenging opportunity in Research and Development problems of an industrial nature.**

Duties include preliminary analysis, design and development of experimental equipment and the design and testing of prototypes. Working knowledge of automatic controls for industrial machinery, high voltage rectifier equipment or high voltage gaseous discharges desirable. Some design and development experience required.

Send resume to H. W. Buswell, Employment Supervisor, Koppers Company, Inc., Metal Products Division, P.O. Box 298, Baltimore 3, Maryland.



National builds lifting magnets to stay in service.

The coils are *monolithic*, triple insulated and bonded with high-temperature, void-free resin.

They're watertight to prevent moisture reaching the coils. The plate is anchored to the magnet case with continuous welds around inner and outer edges.

They're rugged to withstand severe heat cycling and shock.

Check National for your lifting magnet requirements. For more information call Columbus plant ... HUdson 8-1151 ... or the nearest National field engineer.
The Specialists in electric coils/repair service

National repairs magnets of any origin, size or shape.

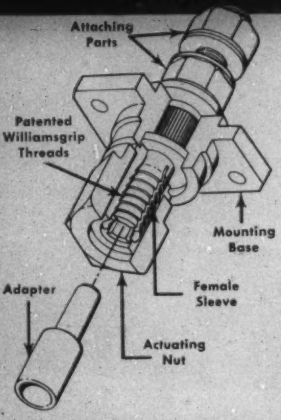
Average Hot Lifting Capacity	55" Pounds	65" Pounds
Slabs, billets	53000	68000
Skull cracker balls	23000	38000
Machine cast pig	3000	3700
No. 1 heavy melting steel scrap	3200	3500
No. 2 melting steel	2000	3500
No. 1 machinery scrap (cast iron)	1700	2400
Cast iron borings	1700	2400
Steel turnings	1000	1200

National Electric Coil

DIVISION OF McGRAW-EDISON COMPANY • COLUMBUS 16, OHIO
Electrical Engineers • Manufacturers of Electric Coils, Insulation, Lifting Magnets
Redesigning and Repairing of Rotating Electrical Machines

McGRAW EDISON

WILLIAMSGRIP
single circuit
quick
disconnect



Williamsgrip electrical connectors provide quick connect and disconnect with a flick of the wrist... plus full positive connection insuring maximum conductivity without the use of springs, slip joints or friction methods.

The patented Williamsgrip construction and special thread design prevents slippage and corrosion, resulting in cooler operation, greater reliability and longer life.

The self-wiping action of the connector eliminates arcing and excessive heating, and allows the connector to operate from 5° to 25°F cooler than the cable, even under conditions of 100 percent overload. Both connectors and adapters are constructed to withstand severe environmental conditions, and have successfully withstood temperatures over 2000°F.

These high current, single circuit connectors covering a wide range of wire and cable sizes have proved their reliability over more than a decade of versatile, rugged service for a wide variety of requirements in the military, industrial and commercial fields.

Write today for AiResearch Product Catalog on "Electrical Connectors."

THE GARRETT CORPORATION
AiResearch Manufacturing Division
Los Angeles 45, California

Industrial Notes...

ITT
New York, N.Y...

A shoe-box-size television camera designed to withstand nuclear radiation for long intervals without damage has been introduced by International Telephone and Telegraph Corp. (ITT), 67 Broad St., New York 4, N. Y. The camera permits close inspection of nuclear reactors where radiation is too intense for observation windows and where it is not desirable to use periscopes or other conventional means of inspection. The camera was built by ITT's Industrial Products Division, San Fernando, Calif. The new camera allows atomic radiation to pass through it without harmful effects because of the special elements with which it is constructed. These include aluminum, magnesium, silicon, titanium, and zirconium. The nonconventional circuitry has six ceramic components, one a small ceramic tube. The picture pick-up tube is of the type called a vidicon, and is specially made of quartz. The camera's lens is made either of cerium and silica or of silica alone, depending upon how the lens is to be used. Lens aperture settings and focus are adaptable to remote control. Complete cooling, under intense heat, is made possible by a flow of gas through a heat exchanger built into the aluminum housing.

3M
St. Paul, Minn...

A cushion against rapid accelerations, violent motions, and abrupt decelerations for the Atlas missile's continuous telemetering equipment is provided by a fluorochemical inert liquid, Fluorochemical *FC-75*, a product of Minnesota Mining and Manufacturing Co. (3M), 900 Bush Ave., St. Paul 6, Minn. The telemetering device, developed by Speidel Corp., Industrial Division, Providence, R. I., can report constantly, any preselected conditions, such as temperature, strain, stress, vibration, or air pressure, through suitable pickups. The sealed unit contains a magnetic tape system that is capable of continuous recording, playback, and erasure of telemetering signals on a continuous loop of tape.

Eastman Kodak Co.
Rochester, N.Y...

A 160-foot lens tunnel is one of many special research features being built into a new 8-story physics building at Kodak Research Laboratories, Rochester, N. Y. The tunnel will be used in research on lenses and optical systems. Its length is essential because in testing a new lens design, an observer or instruments must be far enough from the light source to have it appear as a single point of light. The tunnel is insulated and covered with 3 feet of earth to keep interfering heat waves to a minimum; it is located at basement level, outside the building proper, so it will be free of vibrations from street traffic that might affect delicate measuring instruments. Another antivibration provision is that heating and ventilating motors will be kept to minimum size.

Yardney Electric Corp.
New York, N.Y...

Several hundred extremely compact Silvercel silver-zinc batteries have reached record-setting ocean depth in the U. S. Navy's bathyscaph, *Trieste*, now exploring the Pacific Ocean. The miniaturized batteries, manufactured by Yardney Electric Corp., 40-50 Leonard St., New York, N. Y., supply electric power for a variety of operational apparatus and all instrumentation in the bathyscaph, including external lights and electronic flash and camera; motors and ballast operations; and internal electronic equipment such as water current meters, echo sounders, salt and oxygen content meters, temperature meters, underwater sound telephone, and depth meter.

B. F. Goodrich Chemical Co.
Cleveland, Ohio...

Pliers with vinyl cushions mounted next to the cutting edges are helping to reduce the hazard of flying wire when cutting electrical or spring wire. Developed by Utica Droy Forge & Tool Division of Kelsey-Hayes Co., the plier jaws are cushioned with Geon vinyl, a product of B. F. Goodrich Chemical Co., 3135 Euclid Ave., Cleveland 15, Ohio. The vinyl cushion snugly grips cut-off lengths of wire until pressure is released on the plier handles. The Geon vinyl cushion is held securely and permanently to the metal plier jaws with milled serrations. The pliers are particularly valuable when working on electric or electric equipment. The cushioned jaws hold the short ends of wire and prevent them from getting into equipment being assembled or repaired.

(Continued on page 52A)

The trick is in the adhesive. CDF's Di-Clad® printed circuit boards are tested for bond strength in this precision machine.

CDF has developed special adhesives for bonding copper foil to laminated plastic boards. These adhesives produce high peel strength, have excellent hot solder resistance, etch cleanly, and provide high insulation resistance.

In addition to its own adhesives, CDF makes resins and papers. This extends quality control several steps beyond simple pressing operations . . . provides you with Di-Clad boards of excellent and uniform properties.

CDF manufactures the largest selection of grades to meet every major civilian and military requirement.

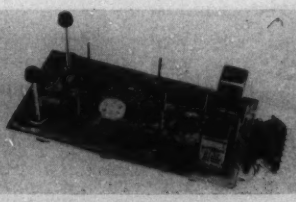
In addition to Di-Clad printed circuit boards, CDF has special combination materials to solve extra troublesome problems. Example: asbestos bonded vulcanized fibre for circuit breaker arc chutes where the fibre quenches the arc and the asbestos guarantees fire resistance.

If you don't see the grade you want in CDF's catalog in Sweet's PD file, write us.

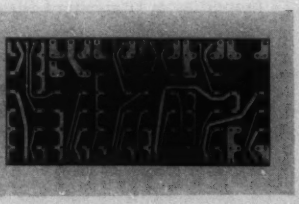
CONTINENTAL-DIAMOND FIBRE

A SUBSIDIARY OF THE Budd COMPANY • NEWARK 86, DEL.
In Canada, 46 Hollinger Road, Toronto 16, Ont.

Vibration-free plug bases, fabricated by CDF. A special bond of CDF Dilecto laminated plastic and rubber.



High reliability printed circuits for military applications. Made from CDF's glass-base Di-Clad laminated plastic.



Low-Cost commercial circuits. Made from CDF's paper-based Di-Clad copper-clad laminate.

Discover the advantages of GLASTIC®!

GLASTIC Class B electrical insulation offers material savings, product improvement

Save the cost of excessive thicknesses of phenolic laminates! Glastic Grade TS—as well as the 10 other standard Glastic grades—offers up to 20 times the impact strength of phenolic laminates. This high impact strength allows the use of thinner sections while still providing a higher factor of safety. Thinner sections mean outstanding material-cost savings.

The Glastic engineering staff is ready to help you investigate the savings and product-improvement you may make by specifying Glastic fiber glass reinforced polyester laminates. Tell us your requirements; we'll send free samples for your evaluation. Or write for our new chart that lists 28 physical, thermal and electrical properties of 11 standard Glastic grades.

GLASTIC
GLASS REINFORCED PLASTIC
tm

THE GLASTIC CORPORATION

4312 Glenridge Road • Cleveland 21, Ohio

Laminates • Custom Molding • Extruded Shapes • Channel Stock • Insulators

Industrial Notes

(Continued from page 50A)

Melpar, Inc.
Falls Church, Va. . .

A patent for an improved single-lens photoelectric device has been awarded to Melpar, Inc., Falls Church, Va., and W. P. Asten, senior engineer at the electronics firm. Principal aim of the invention is to control the projected and reflected light path of a photoelectric arrangement by confining an effective light beam in a single lens. It is an improved version of the photoelectric control circuit which requires at least two lenses. The new system, developed by Mr. Asten, consists of a polished cylindrical rod of quartz or a plastic material through which guided light beams are more easily and accurately aligned with the object and cell. As a result, the device can be used where conventional photoelectric unit use is impossible or impractical.

Pall Corp.
Glen Cove, N.Y. . .

Porous silver is now available in production quantities from Micro Metallic Division of Pall Corp., 30 Sea Cliff Ave., Glen Cove, N. Y. Standard sheet sizes are 6 by 9 inches, with thickness available from $\frac{1}{32}$ to 1 inch. Porosity grades range from a nominal 2 microns to a nominal 55 microns, based upon 98% removal of all particles larger than the nominal rating. In addition to porous silver, Micro Metallic manufactures porous sheets of other precious metals.

Bohn Aluminum & Brass Co.
Detroit, Mich. . .

AL-dec, a new fabricated aluminum product, has been introduced by Bohn Aluminum & Brass Corp., 1400 Lafayette Bldg., Detroit 26, Mich. This functional and decorative grillwork results from a process which creates symmetrical perforations and patterns in aluminum shapes. Because AL-dec can be produced in a variety of patterns and colors, at minimum tooling costs, it has wide appeal to industrial designers and architects for household appliances, exterior and interior construction, air conditioning, air handling units in heating and ventilating, and automotive uses. Its flexibility offers a broad range of new design treatments in many other industrial and commercial areas. For AIA File No. 15L illustrating designs and specifications for AL-dec, write to the company.

(Continued on page 62A)

"Meggers"—courtesy James G. Biddle Co., Philadelphia, Pa.

JOINTS AND TERMINATIONS ON HIGH-VOLTAGE CABLE

emoved semi-conducting particles. The meter eadings will show that a moment of buffing is all hat's needed to complete surface preparation for ape build-ups and the most reliable splice or ter- nination possible today.

The planned research and production program which brings you this outstanding cable develop- ment is also responsible for the equally important levelopments in Butyl rubber insulation com- pounding, and extruding, which have produced he best possible balanced design and construction n high-voltage rubber-insulated cable obtainable oday—Anaconda Durasheath.

For more details, write for Anaconda Bulletin DM-5903, covering Durasheath High-Voltage Cable and DMS-5566, 5720 & 5735 dealing with the splicing & terminating of Durasheath Cable. Contact your nearest Anaconda Wire & Cable Company District Office, or write to: 25 Broadway, New York 4, N. Y.

60238 Rev.

ASK THE MAN FROM

ANACONDA®

ABOUT DURASHEATH® CABLE

The Solution:

A GLENN PACIFIC INDUSTRIAL POWER SUPPLY

One of 10 Glenn Pacific Power Supplies supplied to the U. S. Navy for conversion of 3-phase 460 v. shore power to 120/240 v. dc for shipboard use; rated at 180 kva, continuous duty.

If available power as it comes from the line won't meet your needs, there's a good chance we can help solve your problem—and save you hours and dollars in the process.

As a pioneer in the development of heavy duty power supplies for automatic welding and similar industrial processes, we have three big advantages to offer. First, a lot of hard-earned experience that can save you costly mistakes. Second, a wide range of pre-engineered, custom components (fixed and variable-voltage transformers, heavy duty rectifiers, power capacitors, inductors, etc.) from which we can build a specialized power supply. Third, excellent facilities for designing and producing special components as required.

THE FIELD WE COVER... In general, power supplies rated from 15 kva up; input single, two or 3-phase ac; output either fixed or variable voltage, ac or dc. Constant potential, constant current, normal or high inductance (fixed or variable) designs available.

For typical examples of what we've done, and a better idea of what we can do for you, write now for our latest Industrial Power Supply bulletin. Please address Dept. 135.

GLENN PACIFIC

POWER SUPPLY CORPORATION

703 - 37th Avenue • Oakland, California • Phone: KEllog 2-7404

Eastern Office: 221 Dukes Rd., Rahway, N. J. • Midwestern Office: 640 So. York, Elmhurst, Ill.

Industrial Notes

(Continued from page 52A)

Electronic Engineering Co. Santa Ana, Calif. . .

An electronic data-processing system is making it possible for two computers to "talk" to each other in a common electronic mathematical language at the U. S. Navy David Taylor Model Basin near Washington, D. C. The *ZA-100*, designed and manufactured by the Electronic Engineering Co., 1601 E. Chestnut Ave., Santa Ana, Calif., performs 13 electronic data translations. The Translator enables two computers, the IBM *704* and Remington Rand Univac, to interchange mathematical data freely or to process raw scientific data.

Kent Manufacturing Corp. Newton, Mass. . .

A high-speed attaching machine, which is said to install a wide variety of terminal styles on any wire size, 22 through 10, by simply turning two selector dials, is offered by the Kent Manufacturing Corp., a subsidiary of The Thomas & Betts Co., 188 Needham St., Newton 64, Mass. According to the manufacturer, this single machine will install ring, spade, fork, hook, snap-on, or snap-in terminals, with or without insulation grip. A change in wire size is accommodated by turning selector dials which automatically provide the necessary adjustments in staking pressure, without any machine set-up changes on the part of the operator.

Budd-Stanley Co. Long Island City, N.Y. . .

The completion of a new microwave antenna pattern range that provides greater testing accuracy and efficiency because it operates entirely indoors, has been announced by Budd Meyers, general manager of the Budd-Stanley Co., 43-01 22nd St., Long Island City, N.Y., designers and manufacturers of microwave transmission equipment. Unlike outdoor ranges, with uncontrollable weather, radiation noise, and other interference variables, this indoor range permits more precise antenna measurements because test conditions are constant and outside interference is completely eliminated. The indoor range also puts system and antenna production on an efficient, planned basis. Antenna tests can be conducted round-the-clock, no matter what the weather, in contrast to outdoor ranges which operate only in fair weather.

(Continued on page 63A)

102*

**102 — that's the number of Nelson high voltage starters* in use at just one of the many refineries using Nelson electrical control equipment.

This one refinery has been using Nelson starters for nine years.** What better evidence of complete satisfaction could be desired? Other industries such as paper mills, water and sewage pumping plants, and cement mills have also found that Nelson high voltage starters gave them the dependability and easy maintenance and installation so important to low cost operation.

This record of proven performance again confirms the fact that Nelson is

BIG ENOUGH TO PERFORM SMALL ENOUGH TO CARE

Be sure to let your Nelson representative figure your next job. You will find him listed in the Yellow Pages of major city telephone directories.

Write for your copy of the Nelson Pictorial Index.

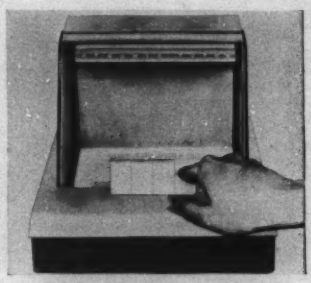
*** Ask your Nelson man for the facts on this installation.*

NELSON *Electric* MANUFACTURING CO.
TULSA, OKLAHOMA
P. O. BOX 5385 RIVERSIDE 2-5531

Industrial Notes
(Continued from page 62A)

General Atronics Corp. Bala-Cynwyd, Pa. . .

A new automatic teaching device designed to increase the effectiveness of the instructor in a wide variety of learning and training situations is announced by Atronic Learning Systems, General Atronics Corp., 1 Bala Ave., Bala-Aynwyd, Pa. Called the Atronic

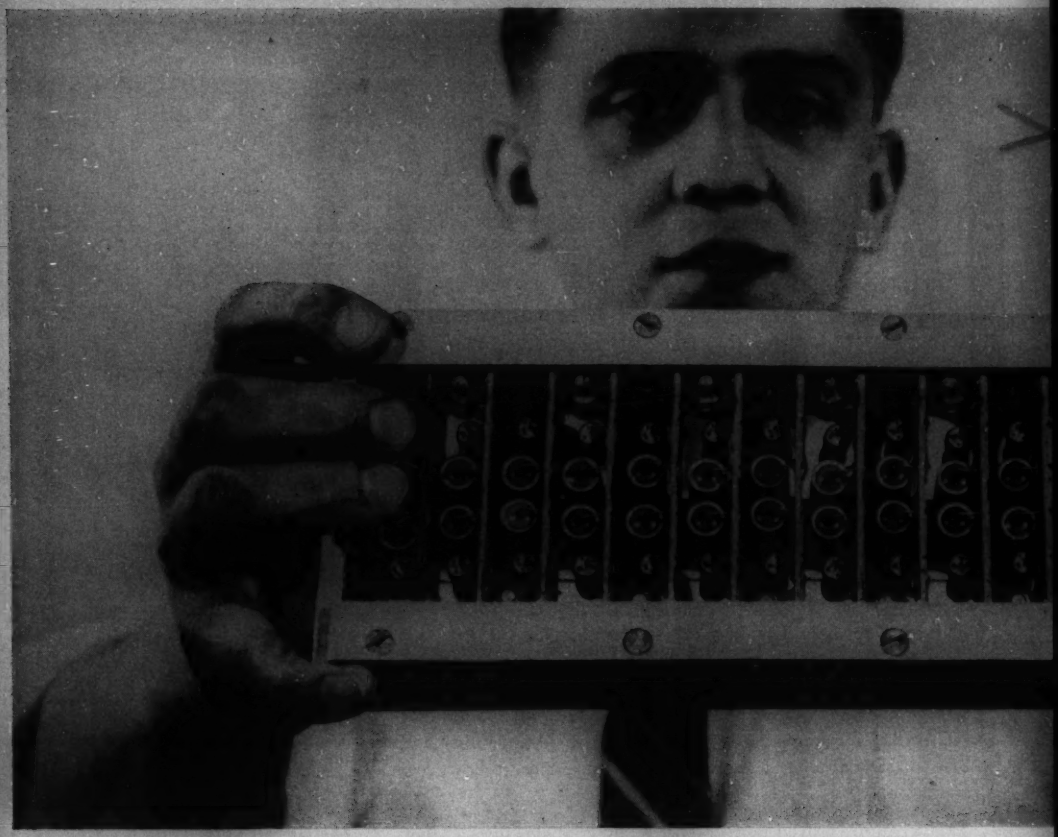


Tutor, the new machine is a simple, reliable, all mechanical unit about the size of a small adding machine, which presents step-by-step text material to the student or trainee at a rate corresponding to his abiliy to absorb it. The Tutor also tests the student on the subject matter, and measures his progress.

The Garrett Corp. Los Angeles, Calif. . .

Development of a microwave training unit, designed to help bridge the gap between the science classroom and the industrial laboratory, has been announced by the Airsupply-Aero Engineering Division of The Garrett Corp., 9851 Sepulveda Blvd., Los Angeles 45, Calif. The nationwide engineering service organization will handle sales for Sigma Electronics Research Corp., developer of the unit which provides a complete undergraduate-level laboratory course in microwaves. The microwave training unit is an assembly of power source, transmission, and receiving components of extreme accuracy. It provides the basic stages of a complete microwave system and permits a comprehensive demonstration and analysis of microwave theories and techniques. An excellent research tool, the microwave training unit is useful for studying the rotational energy bands of gases, radome characteristics, design of new-type antennas, characteristics of solid-state devices, etc.

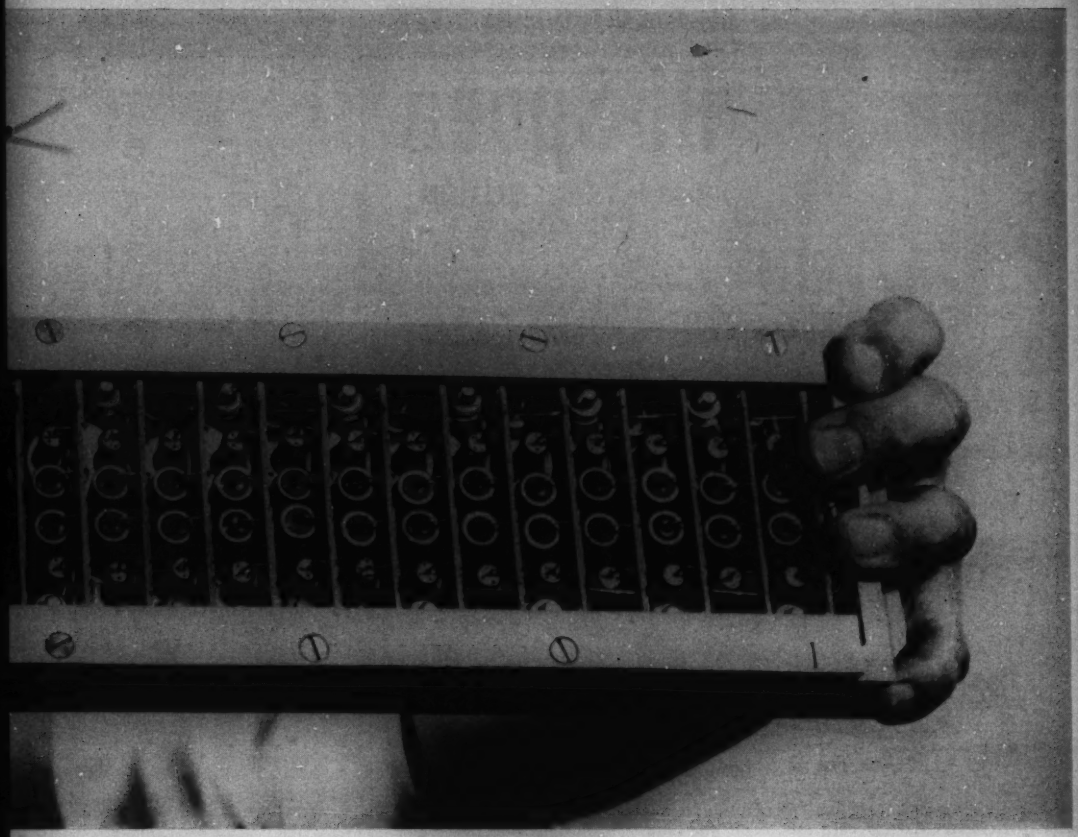
(Continued on page 66A)



10,000,000 FAILURE-FREE STACK-HOURS!

RELIABILITY PROVEN BY 14,000 KW IN FIELD APPLICATIONS

WESTINGHOUSE SILICON HIGH-VOLTAGE RECTIFIER STACKS



Westinghouse silicon rectifier stacks offer the most reliable source of high-voltage rectified power available today. In precipitator applications alone, more than ten million stack-hours have been achieved without a single stack failure. Exclusive Westinghouse design features guarantee uniform division of reverse voltage, provide optimum transient, steady state, and overload characteristics. Stacks assembled in compact, unitized packages take less space, require minimum maintenance, operate in ambient temperatures as high as 110°C. Stacks are available in current ratings from 1.2 Amps to 18 Amps, and in PRV ratings from 9.6 KV to 35 KV. For extremely high voltage requirements, stacks may be connected in series (up to three stacks without additional capacitance compensation).

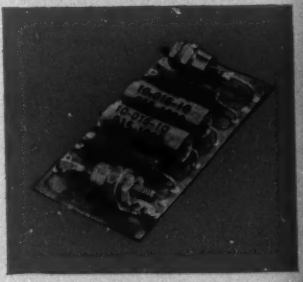
For full information, or engineering assistance in your installation, contact your local Westinghouse representative, or write: Westinghouse Electric Corp., Semiconductor Department, Youngwood, Pennsylvania.

YOU CAN BE SURE... IF IT'S Westinghouse

Ad SC-4104

MIL TYPE COMPONENTS

Unique Westinghouse modular inserts feature MIL Type shunting resistors, capacitors, and mounting boards. All components are 100% tested before and after assembly.

APPLICATIONS

- Electrostatic precipitators
- Radio broadcasting transmitters
- Radar transmitters
- Ultrasonic transducers
- Radar pulse forming networks